Green roofs can be a good option for reducing heat gain and loss in new and existing buildings. This study evaluates the energy performance in a building with different insulation levels and green roof designs of varying growing media depths and plant canopy densities. Furthermore, it attempts to quantitatively identify the effects of green roofs on existing buildings with low insulation levels.

METHODOLOGY

Simulation program

This study uses the green roof module in EnergyPlus to evaluate the energy performance of buildings with green roofs. EnergyPlus software is a widely accepted dynamic simulation engine for the modeling and simulation of building energy performance evaluation. EnergyPlus uses simultaneous simulations, allowing the representation of HVAC calculations in each time step of the building load calculations (DOE 2013).

During the period 2004–2007, researchers at Portland State University developed a physical energy balance simulation module to represent green roofs in a building energy simulation software. This module was integrated into EnergyPlus and in 2007, it became a part of its standard release. The green roof module in EnergyPlus was developed by Sailor (2008) for the quantitative performance evaluation of buildings with green roofs. The energy balance of the model is dominated by solar radiation. The solar radiation is balanced by heat and moisture transport in vegetation, solar radiation exchange, convention, evapotranspiration, and conduction in the growing media (DOE 2013).

Case study

For this study, a virtual case model was created, which consists of a two-story rectangular shaped building (Figure 1). The model represents a commercial office building. The information required for the energy simulation, such as internal loads (people, lights, and equipment), set temperature, and schedules was entered according to the guidelines for commercial buildings (Table 1). The thermostat set points for heating and cooling were 22 and 28 °C, respectively. Weather data in Seoul, Korea were used.

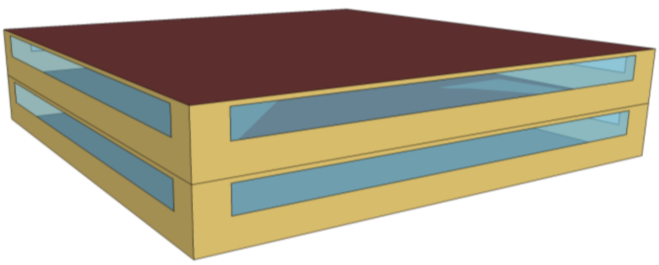

Figure 1. *Schematic of the simulation model*

Table 1. *Summary of the building information data for the simulation model*

		Value	Reference
Internal sources	People	7.5 m^2/person	(ASHRAE 2009)
	Lights	12 W/m^2	
	Equipment	16.1 W/ m^2	
Heating set point		22 °C	(MOLIT 2014)
Cooling set point		28 °C	
Schedules	Occupancy	-	(ASHRAE 2007)
	Lighting and Equip.		

In order to investigate the energy effects of green roofs in buildings with low insulation levels, each case model had different insulation levels and green roof characteristics. The baseline virtual model for existing buildings had low insulation levels according to the energy saving standards of the buildings located in the central district in 2001. At this time, scattered energy standards for the respective building types were integrated into the BDCES (MOLIT 2001, Seo et al. 2011). Another case was established with building envelopes that have higher insulation levels than the baseline, according to the 2014 revision of the building standards for the central district in the Korea peninsula (MOLIT 2014). The construction U-values used in the case study are shown in Table 2.

Table 2. *U-values for building elements specified in the regulations*

Building Element	U-value (W/m^2·K)	
	2001 standard	2014 standard
Wall	0.47	0.27
Ground floor	0.58	0.41
Roofs in the top floor	0.29	0.18
Glazing and door	3.84	2.1

To evaluate the effects of the buildings with green roof, four cases with similar insulation levels were created with different Leaf Area Index (LAI) and soil depth (Case 1–4). LAI varied from 1 to 5 and soil depth varied from 0.1 to 0.5 m. The LAI and the soil depth are critical parameters for the thermal performance of green roofs (Capozzoli et al. 2013). In the four cases with green roofs, the design parameters for vegetation were a leaf reflectivity of 0.22 and leaf emissivity of 0.95. Moreover, the thermal properties of the dry soil of the growing media were as follows: thermal conductivity of 0.2 W/m·K, density of 500 kg/m^3, and specific heat capacity of 1,000 J/kg·K. The green roof model was subjected to typical precipitation schedules in Seoul, Korea. Irrigation was not considered in this study. The test matrix is summarized in Table 3. The fifth case represented a model with the latest insulation standards (higher insulation performance).

Table 3. *Definition of the cases*

Case	LAI	Soil depth (m)	Insulation level	
Baseline	No green roof		Low	2001 standard
1	Low LAI (1.0)	Thin soil (0.1)	Low	
2	High LAI (5.0)	Thin soil (0.1)	Low	
3	Low LAI (1.0)	Thick soil (0.5)	Low	
4	High LAI (5.0)	Thick soil (0.5)	Low	
5	No green roof		High	2014 standard

RESULTS

U-value in roof

Soil depth of the growing layer in the green roof is a key factor affecting roof heat transmission. Table 4 shows the calculated roof U-values of each simulation case. Green roof installation improved the roof insulation performance in all cases. Roof heat transmission coefficients for Cases 3 and 4, with thick soil, were lower than for Cases 1 and 2, with thin soil. Thicker soil depth provided additional insulation performance to the buildings. Conversely, LAI had no effect on the roof heat transfer. Installing green roofs in existing buildings with low insulation levels can improve the roof insulation performance.

Table 4. *Roof U-values of the simulation cases*

Case	LAI / Soil depth (m)	Roof U-value ($W/m^2 \cdot K$)
Baseline	No green roof	0.284
1	Low LAI, Thin soil (1.0 / 0.1)	0.249
2	High LAI, Thin soil (5.0 / 0.1)	0.249
3	Low LAI, Thick soil (1.0 / 0.5)	0.166
4	High LAI, Thick soil (5.0 / 0.5)	0.166
5	No green roof	0.179

Roof surface temperature

Figure 2 illustrates the calculated monthly roof surface temperatures of the simulation cases. There was very little difference in the monthly roof surface temperatures between low (baseline) and high insulation (Case 5) cases, which do not have green roofs, mainly given exposure to similar climate conditions. However, the cases with green roofs showed temperature variations. Unlike non-green roofs, green roofs (Case 1–4) led to reductions in roof surface temperatures during cooling seasons (baseline, Case 5). Increases in roof surface temperatures were observed for these cases during the heating seasons. Similarly, the temperature distribution in high LAI (Case 2 and 4) was lower than those in the low LAI cases (Case 1 and 3), regardless of soil thickness. It is thought that the additional leaves increased transpiration and solar shading. As expected, the green roof system showed heating and cooling load reduction during the heating and cooling seasons. LAI changes greatly affected the roof surface temperatures compared with the variations in soil depth.

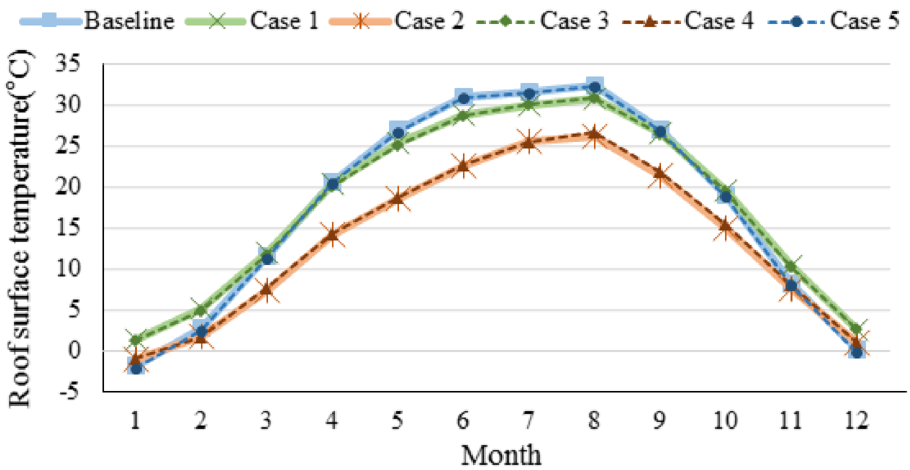

Figure 2. *Roof surface temperature of the simulation cases*

Energy saving effect

Figure 3 shows the heating and cooling load for the top floor of the simulation cases. Regardless of soil depth, a higher LAI had a bigger influence on the reduction of cooling load. This is because higher LAI (case 2 and 4) can reduce heat gain through shading, insulation, evapotranspiration, and thermal mass. Increasing LAI reduces the indoor temperature and the demand for cooling during the cooling season because of increased transpiration and solar shading (Jaffal et al. 2012, Moon et al. 2013). In contrast, lower LAI (case 1 and 3) reduces the heating load during the heating season, due to increased solar irradiation (Kokogiannakis et al. 2011, Moon et al. 2013). The green roof with higher LAI was more effective in reducing heat gain in the cooling season compared with lower LAI values. The soil thickness had the largest effect on heating load. When soil thickness was increased from 0.1 (Case 1 and 2) to 0.5 m (Case 3 and 4), the insulation effect of the added soil reduced the heating load independent of the LAI values. The thicker soil on the roof reduced heat gain and loss in the building (Castleton et al. 2010). Deeper soils may retain more moisture and provide more resistance to heat flow into the building (Sailor and Bass 2014). Thus, increasing the soil depth of green roofs was more effective in reducing heat loss during the heating season. In this study, green roofs provided reductions in building cooling and heating loads. Case 4, with higher green roof LAI and soil depths, showed the most positive effects on both cooling and heating load reduction. The total load in the top floor of Case 4, with a green roof, was less than that of Case 5, with higher insulation levels and no green roof (Figure 3). When the characteristics of the vegetation and soil layer in the green roof are considered appropriately, the installation of the green roof in existing buildings with low insulation levels was found to improve energy performance and conform to the latest insulation requirements.

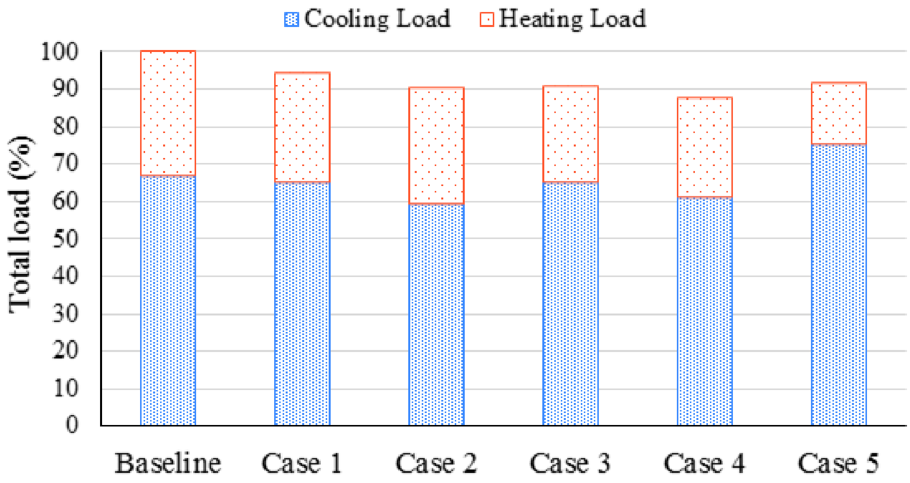

Figure 3. *Cooling and heating loads in the top floor of the simulation cases*

DISCUSSION AND CONCLUSIONS

In the case study, green roofs were found to provide heating and cooling load reductions over the heating and cooling seasons. Installation of a green roof enhances insulation performance with increased soil depth. Increases in soil depth led to observed decreases in heating loads, independent of changes to LAI. This was achieved by providing more resistance to heat flow into the building. Similarly, larger LAI values led to lower roof surface temperatures and cooling loads. This was due to the shading effect that accompanied lower solar radiation and higher transpiration rates, regardless of soil thickness. In older buildings with low insulation levels, the total load in the top floor, with the addition of a green roof, was lower than that of a building with high insulation levels. Therefore, when a green roof system is installed in existing buildings with low insulation levels, the building energy performance becomes similar to a new building with high insulation levels.

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