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# Thermal property measurements for ecoroof soils common in the western U.S.

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**Abstract**

To model the impacts of ecoroofs on building envelope heat transfer accurately, thermal property data for ecoroof soils are needed. To address this need we have measured thermal conductivity, specific heat capacity, thermal emissivity, short wave reflectivity (albedo) and density for ecoroof soil samples over a range of moisture states. To represent a wide range of commonly used ecoroof soils we created eight test samples using an aggregate (expanded shale or pumice), sand, and organic matter in varying volumetric composition ratios. The results indicate significant variability in properties as a function both of soil composition and soil wetness. Thermal conductivity ranged from 0.25 to 0.34 W/(m K) for dry samples and 0.31–0.62 W/(m K) for wet samples. Specific heat capacity ranged from 830 to 1123 J/(kg K) for dry samples and 1085–1602 J/(kg K) for wet samples. Albedo was consistently higher for dry samples (0.17–0.40) decreasing substantially (0.04–0.20) as moisture was added. Thermal emissivities were relatively constant at 0.96 $\pm$ 0.02 regardless of soil type or moisture status. These results are discussed in the context of their impacts on building energy consumption and the importance of including daily and seasonal property variation within models of the ecoroof energy balance.


*Keywords:* Ecoroofs; Green roofs; Building energy; Thermal properties

## 1. Introduction and background

Ecoroofs (vegetated or green roofs) have become increasingly popular in recent years due in large part to the wide range of environmental benefits that they provide. Ecoroof soils absorb stormwater, significantly altering the magnitude and timing of peak runoff—an important consideration in many cities, especially those with combined stormwater and sewage systems [1]. Ecoroofs also positively impact ambient air quality through their impact on air temperatures and particulate deposition [2]. If many ecoroofs are installed throughout a city, the air temperature reductions resulting from cool roof surfaces may combine to produce a measurable reduction in the summertime urban heat island magnitude [3]. Additional benefits of ecoroofs include the generation of habitat and their aesthetic appeal.

While the benefits listed above are important, the focus of the present paper is on the ability of ecoroofs to reduce building energy usage for heating and cooling. Specifically, ecoroofs have a significant impact on the building energy balance through the combined effects of soil insulation, evapotranspiration, convective shielding, and radiative shading of the plant canopy (see Fig. 1). This energy balance, while complicated, is similar in many respects to the energy balance above any forest or agricultural ecosystem. As a result, there are a variety of existing models that may be applicable to ecoroofs when suitably modified to accommodate differences in the lower boundary condition [4,5]. Recent research has investigated the building energy impacts of ecoroofs either through direct measurement of roof heat fluxes [6–8], or through modeling [9,10]. The measurement-based approaches generally use heat flux data to estimate the overall resistance to conduction heat transfer (*R*-value) for the ecoroof construction. While this approach is useful, any model that is to capture the transient nature of heat transfer in an ecoroof system must account for the thermal conductivity, density, and specific heat capacity of the soil itself. Otherwise, the heat storage in the soil – which may be significant in ecoroof constructions – cannot adequately be represented.

While detailed thermal property data for naturally occurring soils are generally available, there is no information in the peer-

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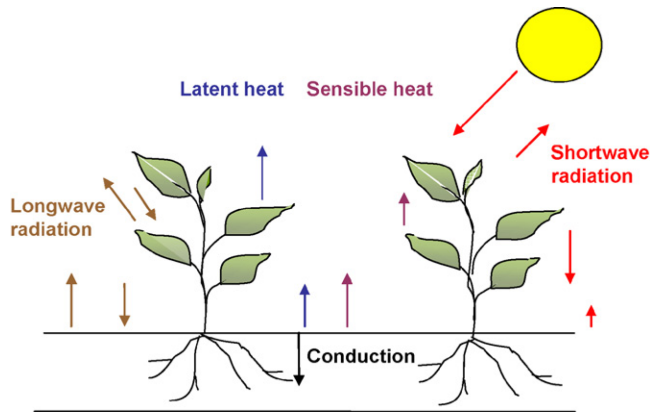


Fig. 1. Simplified representation of the energy balance in an ecoroof canopy.

reviewed literature regarding the thermal properties of common ecoroof soils. As the composition of ecoroof soils is substantially different from naturally occurring soils, it is important that such information be made available so that models of ecoroof energy balances can more accurately represent the relevant heat transfer processes. Also, as these thermal properties vary significantly with moisture content, it is important to measure ecoroof soil thermal properties under multiple soil moisture conditions.

## 2. Methods

The goal of this study was to develop a database of thermal properties for many common ecoroof soils under a wide range of moisture conditions. The properties measured as part of this study were thermal conductivity ($k$), specific heat capacity ($C_p$), short wave reflectivity ($\rho_{sw}$), and long wave emissivity ($\varepsilon_{surf}$).

### 2.1. General experimental design

The first task in the experimental design process was to determine which ecoroof soil samples would be tested. Ecoroof soils typically consist of three components: a lightweight inorganic aggregate, compost, and sand. Opinions vary widely as to the appropriate proportions, aggregate type, and compost type, but the general consensus is that the appropriate soil composition will vary by region and ecoroof design [11–13].

Aggregate selection is largely determined by local availability and cost. Manufactured aggregates include expanded slate in the eastern U.S., expanded clay in the mid-western and eastern U.S., and expanded shale in the western U.S. [13–17]. In areas where pumice is readily available, such as the U.S. Pacific Northwest, it is often used as the main aggregate. Aggregate typically makes up 50–80% by volume of most ecoroof soils. For the scope of this study, aggregate choice was limited to those commonly used in the western U.S.: pumice and expanded shale. Samples tested included either 50 or 75% ''quarter-minus'' (nominal size less than 0.25 in. or 0.64 cm) aggregate by volume.

Appropriate compost selection for ecoroof applications has been a source of debate. Since a significant consideration in ecoroof design is the ability to reduce stormwater runoff without degrading water quality, composts high in nutrients such as animal manure are typically deemed inappropriate as they have been found to produce runoff with unacceptable levels of nitrogen and phosphorus [12]. The use of organic materials in ecoroof applications poses two additional problems as a result of their decomposition: the reduction in soil volume and the development of an organic sludge that interferes with roof drainage, particularly in humid regions. To minimize these problems, industry has begun to reduce compost content in ecoroof soils. In the past, compost typically comprised 10–20% of ecoroof soil. In most recent applications this has been reduced to 0–15%, depending on the climate and soil thickness [12,13]. In addition, high lignin composts are gaining popularity. These composts are produced from peat, bark, sawdust, coconut pith, recycled paper, or yard waste [18]. For this study, an aged yard waste compost was used as large quantities are available in the western U.S. and it is environmentally sustainable. Following the current design trend of low proportions of organic matter, samples tested in this study included 0 and 10% compost, by volume.

The sand component of ecoroof growing media is generally specified as USGA sand. Recommended proportions vary from 0 to 50% depending on the region and ecoroof design [13,15]. In this study, samples included 15, 25, 40, and 50% sand by volume.

The next task was to determine the moisture levels to be tested. To represent a reasonable range of soil moisture states each of the samples described in Table 1 was tested at four moisture levels ranging from ''very dry'' to ''wet''. As the raw materials used in creating samples were not completely dry when received from suppliers the ''very dry'' state was achieved by first thoroughly drying the samples in thin layers using a combination of heating pads and heat lamps. The three additional moisture levels were then created by adding fixed quantities of water: 42, 85, and 225 g water per liter of dry soil for the ''dry'', ''moist'', and ''wet'' states, respectively.

In all, eight ecoroof soil samples were mixed and tested. Four of the samples used pumice as the aggregate and the others used expanded shale. As noted above, for each aggregate four variations of sand and organic matter volume fractions were tested. The sample compositions and corresponding moisture capacities are summarized in Table 1.

Table 1
Composition (% by volume) and moisture capacity of ecoroof soil samples

| Sample no. | Pumice (%) | Expanded shale (%) | Compost (%) | Sand (%) | Moisture capacity (g/g) |
|---|---|---|---|---|---|
| DH01 | 50 | 0 | 10 | 40 | 0.32 |
| DH02 | 50 | 0 | 0 | 50 | 0.30 |
| DH03 | 75 | 0 | 0 | 25 | 0.43 |
| DH04 | 75 | 0 | 10 | 15 | 0.44 |
| DH05 | 0 | 50 | 10 | 40 | 0.23 |
| DH06 | 0 | 50 | 0 | 50 | 0.23 |
| DH07 | 0 | 75 | 0 | 25 | 0.22 |
| DH08 | 0 | 75 | 10 | 15 | 0.24 |