Building and Environment 116 (2017) 130–139

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Sound insulation of lightweight extensive green roofs

Laurent Galbrun [a, *], Léa Scerri [b]

[a] Centre of Excellence in Sustainable Building Design, Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom
[b] École Nationale des Travaux Public de l'État, 3 Rue Maurice Audin, 69518 Vaulx-en-Velin Cedex, France

ARTICLE INFO

Article history:
Received 27 October 2016
Received in revised form
10 February 2017
Accepted 13 February 2017
Available online 17 February 2017

Keywords:
Building acoustics
Sound insulation
Green roofs

ABSTRACT

This paper examines factors affecting the sound insulation of lightweight extensive green roofs. The research had three objectives: (1) To examine the extent to which the sound insulation of lightweight extensive green roofs is affected by the variable conditions of their substrate and vegetation layer (soil's distribution, water content and compaction level); (2) To quantify how sound insulation is affected by the main elements making up the roof (substrate and vegetation layer, drainage layer and added cavity); (3) To identify applications for such roofs in relation to their sound insulation performance. For objective 1, it was found that the variable conditions of the substrate and vegetation layer do not significantly affect the sound insulation properties of lightweight extensive green roofs (variations in R_w of no more than 1 dB). For objective 2, results indicated that the addition of a cavity represents the most effective solution for improving sound insulation (+13 dB in R_w for a 50 mm deep cavity with mineral wool), whilst increasing the amount of substrate or using heavier drainage layers tend to provide more limited improvements in R_w (+3 dB for 25 mm of substrate and +2 dB for gravel vs. lightweight drainage membrane). Finally, regarding objective 3, the systems tested were found to provide appropriate sound insulation for both commercial and residential types of constructions. All the results were obtained from tests carried out on small 1 m^2 samples, so their accuracy and validity will need to be identified through comparisons with large scale tests.

1. Introduction

Green roof systems have become increasingly used in urban spaces, due to their environmental, ecological and visual benefits [1]. They can avoid localised flooding by reducing water runoff [2]; they cool the temperature inside buildings in summer, thanks to evapotranspiration, and act like an additional layer of insulation in winter [3]; they reduce the urban heat island effect compared to traditional buildings [4]; they help remove airborne particles, heavy metals and volatile organic compounds from the local atmosphere and can recreate habitats for enhanced biodiversity in urban areas [5]. They can also provide energy savings, in particular when used to retrofit older buildings [6].

Acoustic benefits of such systems have also been demonstrated within the context of traffic noise mitigation. In particular, acoustic studies have focused on the sound absorption and sound propagation properties of green roofs [7–12], as well as of green walls and vertical greenery systems used on façades [13–15]. These studies have found that green roofs and vertical greenery systems reduce sound propagation compared to rigid roofs/façades, with maximum road traffic noise reductions of approximately 10 dB at mid frequencies around 500 Hz–1000 Hz, for green systems with a length of 8 m [7,13]. Furthermore, research has shown that positive effects of green roofs are only observed at non-directly exposed parts of façades (i.e. at the opposite side of a building compared to the one where the source is present), and that a sufficient green roof area and flat roof are needed to maximise the traffic noise reductions [8]. The configurations of the systems [11], roof thickness [7,10] and vegetation layer [12], have all been shown to be important factors affecting the sound absorption and sound propagation properties of these systems.

Sound insulation is another feature which can be provided by a green roof system, but previous work on the sound insulation properties of green roofs has been very limited so far. Green roofs are multi-layered systems, and it is known that the use of multiple layers takes advantage of losses in transmission between the layers, increases damping, and can potentially reduce the coincidence effect, all of which contribute to increasing sound insulation [16].

* Corresponding author.
E-mail address: L.G.U.Galbrun@hw.ac.uk (L. Galbrun).

http://dx.doi.org/10.1016/j.buildenv.2017.02.008

Furthermore, it is known that the acoustic characteristics of porous materials, such as green roofs' substrates, are affected by factors such as porosity, particle size distribution, moisture content and compaction [17]. The soil's texture also affects the attenuation of sound as it passes through the depth of the soil, and it has been found that lower attenuation occurs in loose dry soils [18]. Furthermore, the interface between the soil and vegetation layer has been identified as affecting the impedance of the system, and therefore the amount of sound transmitted through it [19].

All these previous studies evaluated specific sound insulation properties of green roofs' elements, rather than their overall sound insulation properties which can be quantified by the sound reduction index (known as the sound transmission loss in North America). The latter has been examined by Connelly and Hodgson [20,21], who measured the sound transmission loss of two different extensive green roofs by using the intensity approach of ISO 15186-1 [22]. The sound transmission loss of a reference roof (Roofing Evaluation Module (REM): 75 mm concrete, steel reinforcing, 318 mm Expanded Polystyrene (EPS) insulation) was compared to that of two green roofs consisting of: (1) the reference roof + 75 mm of substrate; (2) the reference roof + 150 mm of substrate. Results showed that, compared to the reference roof, consistent increases in sound transmission loss could be obtained for the thicker green roof (5–13 dB up to 2000 Hz), whilst the thinner green roof could not provide such improvements between 100 Hz and 600 Hz. These findings suggested that green roofs can be used instead of additional ceilings, especially considering their better performance below 125 Hz, as false ceilings (lightweight with cavity not very large) only increase the transmission loss in the mid and high frequency ranges [23,24]. Connelly and Hodgson also quantified the significant benefits of vegetation used over either a wood frame roof (5–13 dB in the 50–2000 Hz frequency range, and up to 8 dB above 2000 Hz) or a lightweight metal deck (up to 10 dB, 20 dB and >20 dB in the low, mid and high frequency ranges respectively) [25]. In this study, the moisture content of the substrate did not affect the transmission loss of the systems tested.

Other studies also examined the sound insulation properties of green walls and vertical greenery [13–15]. Wong et al. [13] found that the insertion loss of vertical greenery systems is higher at low to mid frequencies (in the order of 5–10 dB) due to the absorbing effect of the substrate, while it is smaller at high frequencies due to scattering from the greenery. Azkorra et al. [14] tested the sound insulation of a modular-based green wall, a lightweight system for which a weighted sound reduction index (R_w) of 15 dB was measured. Furthermore, Pérez et al. [15] found that a thin layer of vegetation (20–30 cm) used over a masonry construction can provide an increase in sound insulation of 1–3 dB.

The present study focuses on the sound insulation properties of green roofs, and within that context, the work of Connelly and Hodgson [20,21,25] is the most relevant. In Refs. [20,21] a concrete roof base was used, but lightweight bases are also used in extensive green roofs [25], especially in the retrofitting of existing buildings [6]. These are economical systems typically made of corrugated steel bases or timber joist roofs with plywood or chipboard plates used as the base, and can be found in both residential and commercial buildings. The low mass of such systems can however result in poor sound insulation properties, compared to green roofs constructed over concrete bases. Consequently, a good understanding of the factors affecting the sound insulation properties of lightweight green roofs is critical, in order to be able to provide appropriate design guidance. The present study examined this for a variety of lightweight extensive green roof systems, in view of improving the understanding of how the multi-layered composition of such systems affects their sound insulation. More specifically, the research had three main objectives:

(1) To examine the extent to which the sound insulation of lightweight extensive green roofs is affected by the variable conditions of their substrate and vegetation layer (soil's distribution, water content and compaction level);
(2) To quantify how sound insulation performance is affected by the main elements making up the roof (substrate and vegetation layer (which are the main elements affecting the mass of the system), type of drainage layer used, and presence or absence of a cavity);
(3) To identify applications for the lightweight extensive green roof designs tested, based on their sound insulation performance.

The paper initially illustrates the materials and methods used in the study, followed by the presentation and analysis of the results obtained, and conclusions.

2. Materials and methods

A green roof can be categorized as intensive, semi-intensive, or extensive, depending on the depth of the planting medium and the amount of maintenance needed [5]. Intensive and semi-intensive green roofs have greater depth and can accommodate large as well as small plants, whilst extensive green roof systems typically have shallower system profiles. Due to their minimum maintenance requirements, extensive green roofs tend to be more commonly used [5] and are the only type of green roof considered in this paper. The structure used for tests and the procedures undertaken in this research are illustrated below.

2.1. Test structure

In order to test the sound insulation properties of a typical extensive green roof, the vertical transmission suite located in the acoustic laboratory of Heriot-Watt University was used (Fig. 1). The vertical suite is composed of two rooms: a lower room of 5 m × 4 m × 3 m (60 m^3), and an upper room of 5 m × 4 m × 2.7 m

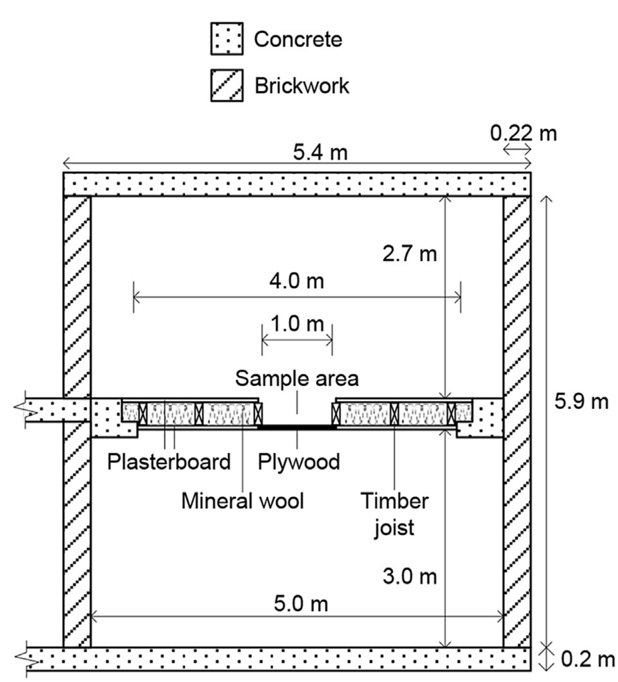

Fig. 1. Section diagram of the vertical transmission suite (not to scale).