Influence of the Types of Grass of Green Roofs for the Design of Thermal Comfort in Buildings

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ABSTRACT

The main objective of the research was to study the effect of the *Stenotaphrum secundatum* and *Zoysia japonica* grasses on the higher and lower environment temperature and lower relative humidity; the secondary objective was to compare whether the *Stenotaphrum secundatum* grass has a greater impact on the environment parameters of comfort than the *Zoysia japonica* species. Six materials were used for the extensive green roof, each one forming a layer of the system, which were placed on the concrete slab and in an upward direction, including: PVC geomembrane, Polyester asphalt carpet, Pumice stone, Planar geodren, Prepared soil with guano, compost, muss, and Substrate. In order to make measurements of the higher and lower ambient temperature, a digital thermometer and lower relative humidity meter was used. *Stenotaphrum secundatum* and *Zoysia japonica* were used as grass species, as they were the most representative of the grasses used in extensive green roofs. The experimentation was carried out for 2 months from September to October of 2021, having built 3 modules of 1000x600mm roofs, including 1module of the concrete roof with ceramic covering and 2 modules of extensive green roof with two types of grass: *Stenotaphrum secundatum* and *Zoysia japonica*. The readings of the environment temperature and relative humidity of the higher and lower part were taken in six points of each module to have a greater number of representative measurements. The watering of the 2 green roof modules with grass was carried out twice a week, applying 5L of water per module. The results indicate that the *Zoysia japonica* grass is the one that presents a better behavior before the higher ambient temperature and that the *Stenotaphrum secundatum* grass behaves better before the lower ambient temperature and lower relative humidity. The conclusions indicate that the *Stenotaphrum secundatum* grass behaves better temperature and relative humidity; the two grass types exhibit different behavior.

Keywords: grasses, *Stenotaphrum secundatum*, *Zoysia japonica*, ambient temperature; relative humidity, thermal comfort, extensive green roofs.

INTRODUCTION

A significant worldwide increase of people living in cities occurred in the last five decades, reaching 37% in 1975, increasing to 48% in 2015 and 55% projected for 2050 by OECD-EC [2020]. This projected growth requires adequate planning of cities considering the construction and development of urban infrastructure. In this context, urbanization is very important for the development of building infrastructure, because its different processes should concentrate on people, the development of economic activities in the city, and the consumption of resources without increasing environmental impacts [Madlener and Sunak 2011].

An important strategy to conceptualize the planning of connected greenspace in urbanized is urban green infrastructure [Davies and Lafortezza 2017], including green roofs, i.e. a system of vegetated surfaces in buildings used to mitigate the impacts of dense urban areas [Teutónio et al.,

2018], such as the evapotranspiration process [Bevilacqua et al., 2020] of the plant-substrate-drainage system which is a fundamental moderator on mass and heat transfer for roof cooling.

The plants, depending on the variety of species, growth typology, and their physiology, complement their effect with the shade provided by the vegetation layer on the roof surface to increase the reduction of heat fluxes. The substrate influences are governed by its material, compaction, porosity, permeability, and size of the soil particles, complemented by the amount of water it contains. The drainage varies according to the type and can be modular plastic panels with a water retention layer, natural granular materials, or materials of recycling [Cascone et al., 2019].

Green roofs present a passive evaporative cooling system that provides the water balance urban catchments [Gwóźdź et al., 2016], the retention of rainwater [Baryła et al., 2019], very high resistance to the heat flow-oriented towards the interior of the spaces [Osuna-Motta et al., 2017], able to reduce it by about 25% [Kwon et al., 2019] and contribute to the reduction of the upper and lower temperature of the buildings [Padilha et al., 2018] caused by excessive solar radiation. The extensive green roof is more used than the intensive type, because its vegetation is drought tolerant [*Köhler* 2006], has low structural load capacity and low implantation costs [Marcato et al., 2018], requires little maintenance [Bevilacqua et al., 2016], shallow substrate (15–20 cm deep) [Cristiano et al., 2021] [FLL 2018] and is intended for aesthetic appeal [Cook and Larsen 2021]. Among the plants used in Brazil, there is the *Zoysia japonica* grass [Ferreira et al., 2016], whereas in Japan the *Sedum* plant and different species of grasses are employed [Kuronuma et al., 2018].

The most used grass species are *Stenotaphrum secundatum* [Lopez et al., 2020], *Zoysia japonica* [Patton et al., 2017], *Zoysia matrella* and *Bermuda* [Wherley et al., 2014], *Poa compressa* [Wolf and Lundholm 2008], *Festuca ovina* [Erwin and Hensley 2019], *Paspalum notatum* [Cardoso and Vecchia 2013], which are very effective in reducing water runoff [Nagase and Dunnett 2012], economical [Hodkinson 2018] and allow attenuating the increase of temperatures during the day and heat dissipation [Jamei, et al., 2021]. One strategy to counteract the heat flow inside the rooms and improve their thermal comfort is to use different species of grasses.

Some investigations have been carried out on the environmental factors of thermal comfort. This paper studied the upper environmental temperature in a green roof with 2 types of grasses *Zoysia tenuifolia* and *Korean velver* which equaled 30.2°C whereas in the concrete roof with ceramic it amounted to 33.4°C, i.e. 9.58% less [Jim 2012].

Similarly, for 2 months and 32 days recovery period, [Beitz 2011] studied the variation of the upper temperature concerning the lower temperature in modules of the *Bouteloua dactyloides prestige* grass for 3 irrigation frequencies of 4 days, 8 days, and 12 days, finding values of 24.4°C, 25.4°C, and 29.1°C, and 17.2°C, 15.1°C, 16.5°C which were 29.5%, 40.55% and 43.30% lower than the upper temperature. The lower ambient temperature in a green roof with 2 types of *Amendoin arachis repens* and *Zoysia japonica* grasses was 29.47°C and 30.33°C which represents a difference between them of 2.92% [Carneiro et al., 2015].

The present investigation studied the influence of the *Stenotaphrum secundatum* and *Zoysia japonica* grass species on ambient temperature and relative humidity in extensive green roof modules with grass; also, it compared whether the *Stenotaphrum secundatum* grass performs better than the *Zoysia japonica* grass to environmental factors of thermal comfort mentioned above.

MATERIALS AND METHODS

Materials

The following materials were used in the 6 layers [Naranjo et al., 2020] of the extensive green roof system: PVC Geomembrane 1000×600×10 mm; Polyester asphalt mat 1000×600×3 mm; Pumice stone 12.5–75 mm; Planar Geodren 1000×600×10 mm; Prepared soil [Wheeler, Osborne 2010]; Substrate with 2 types of grass *Stenotaphrum secundatum* (humid, subtropical) and *Zoysia japonica* (cold resistant).

An MG320 digital laser thermometer model was used to measure the Higher Ambient Temperature (HAT), Lower Ambient Temperature (LAT), and a humidity meter model DM110 was used to measure the Lower Relative Humidity (LRH).

The *Stenotaphrum secundatum* and *Zoysia japonica* grasses were purchased from a greenhouse and had 2–3 months of growth, requiring 4 cuttings of 0.25 m^2 per type of grass.

Modules

The experimental part of the research was carried out on 3 modules: Module 1, conventional concrete slab with ceramic (control roof); Module 2, extensive roof with *Stenotaphrum secundatum*; Module 3, extensive roof with *Zoysia japonica* (Figure 1).

The modules were built on conventional concrete slabs with characteristic compressive strength of 20 MPA at 28 days, with dimensions 1000x600x450 mm, constructed of wood, and placed 1.00m above the ground on an iron table.

The readings were taken at 6 points distributed in the higher and lower part of the 3 modules, each colocated in 2 rows spaced 300 mm apart and 150 mm apart from the sides of the shortest dimension (600 mm), and in the other longest dimension (1000 mm) the separation was 200 mm.

The irrigation of the species was done twice a week for both types of grass, applying 5L of drinking water each time and per type of grass. The temperature and humidity of the environment had a variation of 17–26°C and 46–72%.

The HAT was evaluated for 55 days (control module: ceramic; modules 2 and 3: grass blade); LAT and LRH (control, modules 2 and 3: under the slab).

RESULTS AND ANALYSIS

Higher ambient temperature

Figure 2 shows the average values of 6 daily records of the HAT for the *Stenotaphrum secundatum* and *Zoysia japonica* grass types, and for the control module taken during 55 days. It can be seen that the HAT is slightly higher with the *Zoysia japonica* grass, the value of which reached 24.32°C and compared with 23.93°C and 30.73°C achieved with the *Stenotaphrum secundatum* grass and in the control module, it represents 3.72% greater and 23.81% higher value respectively.

Lower ambient temperature

Figure 3 shows the average values of 6 daily records of the LAT for the *Stenotaphrum secundatum* and *Zoysia japonica* grass types, and for the control module taken during 55 days. It can be seen that the LAT is slightly higher with the *Zoysia japonica* grass, which reached the value of 20.41°C and compared to 20.20°C and 25.93°C achieved with the *Stenotaphrum secundatum* grass and in the control module, it represents 1.04% higher and 27.05% lower value, respectively.

Lower relative humidity

Figure 4 shows the average values of 6 daily records of the LRH for the *Stenotaphrum secundatum* and *Zoysia japonica* grass types, and for the control module taken during 55 days. It can be seen that the LRH is higher with the *Zoysia japonica* grass, which reached the value of 0.72% and compared with 0.70% and 0.69% achieved with the *Stenotaphrum secundatum* grass and in the control module, it represents 1.45% and 4.35% greater value, in both cases.
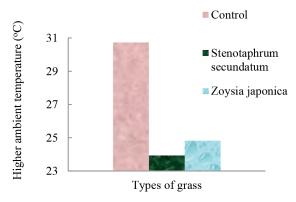

Figure 1. Types of module
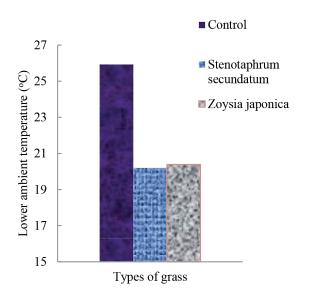
Figure 2. Effect types of grass on HAT

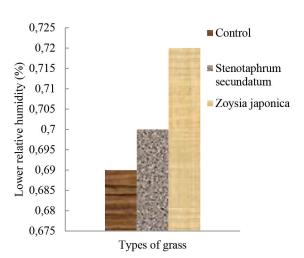**Figure 3.** Effect types of grass on LAT

Figure 4. Effect types of grass on LRH

DISCUSSION

Higher ambient temperature

The variation of results found concerning the HAT for the 2 types of grass used, where the *Zoysia japonica* grass has a higher incidence than the *Stenotaphrum secundatum* grass, represent a behavior similar to other investigations carried out, being in line with [Lundholm et al., 2010] who studied 3 types of grasses from Nova Scotia, finding that the HAT for the *Poa compressa* grass was 23.50°C, for *Deschampsia flexuosa* 23.82°C, for *Danthonia spicata* 24.56°C, and for the control surface 26.59°C, which represents an increase of 1.36% and 4.51% concerning the *Poa compressa* grass; and a decrease of 13.15% concerning the control. Similarly, [Wolf and Lundhol 2008] studied 2 types of grasses from Nova Scotia and 1 type used in Europe and North America, finding that the water losses by transpiration for the same soil moisture gradient in *Poa compressa* grass are 29.62% concerning the *Danthonia spicata* and *Deschampsia flexuosa* grasses.

The HAT difference between the two grass species is because the physiology and morphology of the leaves are different [Blanusa et al., 2013], for example, the *Stenotaphrum secundatum* grass produces a dense turf [Trenholm et al., 2021; Li et al., 2010]; while the *Zoysia* grass forms an extremely dense [Unruh et al., 2016], uniform turf through the production and spread of rhizomes and stolons [Sladek et al., 2009], the product of the higher proportion of dry weight partitioned to stems instead of leaves [Patton et al., 2007], which contribute to better behavior in the face of the external temperature.

Lower ambient temperature

The variation of results found concerning the LAT for the 2 types of grass used, where the *Stenotaphrum secundatum* grass has a higher incidence than the *Zoysia japonica* grass, represents a behavior similar to other investigations carried out, being in line with [Vieria 2014] who found a LAT of 34.1°C for a roof with fiber cement tile and 31.7°C for a roof with the *Zoysia japonica* grass type, which represents 7.0% lower value. Similarly [Cordoni 2015] found a LAT of 21.1°C for a roof with the *Zoysia tenuifolia* grass and 22.7°C for a roof with a concrete slab, which represents 7.1% lower value.

The difference in LAT between the two species is due to the different leaf area index of the leaf [Kemp 2017]; thus the *Stenotaphrum secundatum* species having a leaf width of 4 to 10 mm, provides a higher index per m² of soil that affects the reduction of the indoor temperature, against the *Zoysia japonica* species that presents a smaller leaf width of 2 to 4 mm [Hitchcock, Chase 2013].

Lower relative humidity

The variation of results found concerning the LRH for the 2 types of grass used, where the *Stenotaphrum secundatum* grass has a higher incidence than the *Zoysia japonica* grass, represent a behavior similar to other investigations carried out, being in line with those found by [Lohmann 2008] who found a 3.24% decrease in absolute humidity in a green roof covering compared to a concrete slab covering.

This cooling effect is mainly due to the evaporation and shading effect of the vegetation [Alves et al., 2015], whose physiological responses to shade include the decreased evapotranspiration [Wherley et al. 2013]; for the *Zoysia japonica* grass its tolerance low [Wherley et al. 2011] and for *Stenotaphrum secundatum* it is higher.

The difference in LRH between the two species may be because *Zoysia japonica* is a temperate climate species resistant to cold; while *Stenotaphrum secundatum* is a warm, humid (subtropical) climate species that have LRH.

CONCLUSIONS

The variation of the environmental parameters of thermal comfort was studied for two types of grass in green roof modules, finding that the best behavior in HAT is obtained with the *Zoysia japonica* grass, which represents 24% lower temperature than that on the surface of a concrete slab. The *Stenotaphrum secundatum* grass has a more important incidence in the LAT related to the decrease of the heat flux by approximately 28%, which contributes to lower thermal energy transferred from the roof to the interior. Greater efficiency in reducing LRH was obtained with the *Stenotaphrum secundatum* grass, providing better thermal comfort by 1.5% compared to a concrete surface.

From the comparison of the *Stenotaphrum secundatum* and *Zoysia japonica* grasses, it can be seen that the *Zoysia japonica* and *Stenotaphrum secundatum* grasses reduce the surface temperature and contribute to the reduction of indoor and outdoor ambient heat, the *Stenotaphrum secundatum* grass being more efficient for environmental comfort in buildings. In general, it can be concluded that the results obtained present the same trend as the investigations carried out, with the values found within the expected ranges.

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