Urban and Regional Planning
2024, Vol. 9, No. 3, pp. 88-95
https://doi.org/10.11648/j.urp.20240903.13

Research Article

Effect of Covers Terraces on Humidity Inside Buildings: Case Study in the City of Rabat

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Abstract

Covers terraces are becoming increasingly widespread, given their advantages in terms of regulating the building's climate and the speed at which rainwater runs off. The first article in this research consisted in selecting plantations capable of withstanding the conditions of terraces, while the second article dealt with the effect of terrace coverings on the temperature inside buildings. Although sedums are the most widely used plant species for covering building terraces and have shown the best resilience and adaptability for green roofs, additional ecosystem services can be provided by native plants, suggesting future research to optimize plant composition and cover for sustainable green roofs. This research compares the effect of terrace coverings of different thicknesses on humidity inside buildings. This research compares the effect of terrace covers with different thicknesses (5 cm and 10 cm), on humidity inside buildings during the four seasons. The results show that the 10 cm thick terrace cover has a humidity-increases effect during the warm period (+ 3,01%). The 5 cm thick terrace cover has a humidity-reducing effect during the cold period (-0,2%). Also, the maximum relative humidity of the 10 cm thick cover decreased by 9.48%, and the maximum relative humidity of the 5 cm thick cover decreased by 13.25%.

Keywords

Planted Terraces, Building, Humidity, Terrace Cover, Nature Based Solution

1. Introduction

Terrace covers are seen as effective environmental solutions for mitigating extreme heat and regulating relative humidity, particularly in urban environments «Nature-based Solution» (NbS) [1, 2]. Although green roofs require higher initial installation and maintenance costs than conventional and cool roofs, they offer a longer lifespan. The benefits of green roofs [3, 4] include reduced runoff, thermal and acoustic insulation, stormwater management and a longer lifespan [5]. In addition, increasing urban vegetation cover through green roofs improves air and water quality, increases carbon absorption, enhances building aesthetics and provides potential natural habitat [6, 7]. The environmental benefits of green roofs are

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Received: 19 April 2024; **Accepted:** 3 May 2024; **Published:** 29 July 2024

largely coupled to regional climatic conditions [8, 9], such as atmospheric temperature and CO_2 concentration [10], which are expected to increase over the coming decades [5]. The aim of this study is to assess the effects of different roof coverings on relative humidity inside buildings. The term relative humidity (RH) expresses the relationship between the moisture content of air at a certain temperature and the moisture content of moisture-saturated air at the same temperature. It is expressed as a percentage from 0 to 100 [11]: 0% RH means that the air is absolutely dry, that its moisture content is zero, and 100% RH means that the air has reached saturation point, the dew point. Any additional humidity will precipitate (condensate) and form water droplets. Relative humidity is directly related to water activity (AW), on a scale from 0 to 1. The relationship is as follows: RH = AW × 100. Condensation of humidity at the dew point: When cold surfaces are surrounded by humid air, water vapor condenses once the temperature drops below the dew point. This gives the impression that the surface is sweating [11].

2. Materials and Methods

2.1. The Experimental Protocol

The terrace concerned by the experiment is located in the city of Rabat, Morocco, at the Hassan II Agronomic and Veterinary Institute, specifically the terrace of building J. We have chosen a terrace that offers the possibility of taking climatic parameters for 14 rooms with the same surface areas. The aim is to measure the variation in temperature [12] and humidity in each room as a function of the type of terrace covering, compared with a control room with no covering. Each room will be fitted with a transmitter thermo-hygrometer to measure the variation in humidity depending on the season and the type of roof covering. Two other transmitting thermo-hygrometers will be installed directly on the terrace to measure the relative humidity. The measurements are based on the following conditions (First factor: Type of roof covering): Pebble (St), Gravel (Gr), Plant container (Pl). (Second factor: Thickness of the covering layer of the terrace Th) Th = 5 cm, or 10 cm. After combining the factors studied: Modalities and levels, we obtain the treatments presented in Figure 1. Each treatment is repeated twice.

The parameters to be monitored by progressive readings are humidity of the covered premises, ambient humidity of the air on the terrace. The characteristics of the units and their repetition on the terrace of building J are shown in Figure 1.

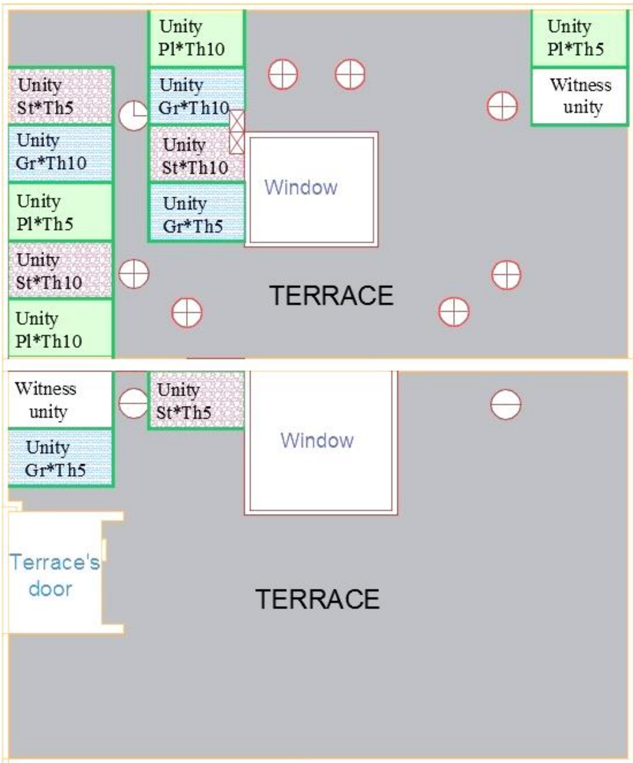

Figure 1. Distribution of units on the terrace.

2.2. Materials

The separation used is a PVC "GREENBORDER" edging, measuring 9 m in length and 0.2 m in width. The grass border was fixed to the terrace using red bricks laid on the terrace. The experimental protocol required two plot units of pebbles and gravel, with two repetitions. The first pebble plot unit contains a 5 cm thick layer of pebbles, and the second contains a 10 cm thick layer of pebbles (Figure 2a). The same principle applies to the two gravel units, with the first unit containing a 5 cm thick layer of gravel and the second containing a 10 cm thick layer of gravel (Figure 2b).

Figure 2. Materials used: (a) pebble parcel units, (b) gravel parcel units.

The plant species [13, 14], used in the protocol experimental are the results obtained in my first research experiment entitled: "selection of plants adapted to building terraces on the basis of their growth" [15]. The experimental protocol involved two plot units of plant containers, with two replications. The first plant container plot contained a 5 cm thick layer of substrate, and the second contained a 10 cm thick layer of substrate. The species used in the experimental protocol are: Kalanchoe thyrsiflora (Figure 3a), Echeveria australis rose (Figure 3b) and Sedum rupestre 'Angelina' or Sedum reflexum [16] (Figure 3c).

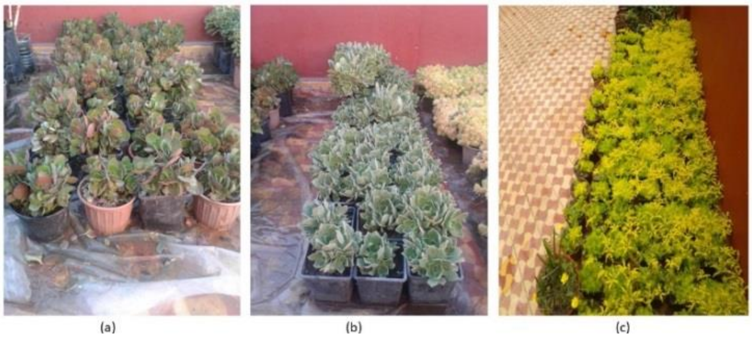

Figure 3. *The species used in the experimental protocol: (a) Kalanchoe thyrsiflora; (b) pink Echeveria australis; (c) Sedum rupestre "Angelina" or Sedum reflexum [15].*

Figure 4. *Internal units, thermo-hygrometer record transmitters and USB receivers.*

Professional thermo-hygrometers with data logging functions were used (Figure 4). These logging functions are, firstly, temperature (accuracy ± 1℃) and humidity monitoring, which contains an indoor temperature range of 0 to +50 degrees (resolution 0.1 degrees) and an indoor humidity measurement range of 1% to 99% (resolution 0.1 degrees, accuracy ± 3% between 35 and 75%). Secondly, dew point indication, min./min function, with time and date recording. Finally, the option of expanding to 8 radio channels (8 transmitters) with a humidity and temperature transmitter with cable or probe for temperature display (Figure 4).

2.3. Data Analysis

Recordings by the thermo-hygrometers began on 1 February 2021 and will continue until the end of January 2022. These consist of two central units and fourteen sensors (a total of 16 recorders). Two transmitters on the terrace of building J to record ambient temperature and relative humidity. The two central units and twelve transmitters are placed inside the rooms on the top floor of building J. Each transmitter records the temperature and relative humidity of the rooms, which are covered with a 5 cm thick pebble, or a 10 cm thick pebble, or a 5 cm thick gravel, or a 10 cm thick gravel, or a 5 cm thick plant container, or a 10 cm thick plant container, without forgetting the control room with no cover. Each experimental unit was repeated twice. The analysis focuses on the climatic data (relative humidity) recorded over a full year: February 2021-January 2022. The data is recorded at hourly intervals (24 hours a day) and is collected regularly. Relative humidities are in percent (%). The relationships between the variables were analysed using standard statistical analysis methods (linear regression, ANOVA, correlation tests, etc.). The data was first processed sensor by sensor, then compared between the different covers (pebble, gravel and plant containers) and the two thicknesses (5 cm and 10 cm). Finally, the data was compared with the climatic data for the ambient air on the terrace and the climatic data for the controls.

3. Research Results

The air maximum relative humidity curve shows that the highest ambient maximum relative humidity is recorded during the months of February and October 2021 (97%), and the lowest ambient maximum relative humidity is recorded during the month of January 2022 (64%) (Figure 5).

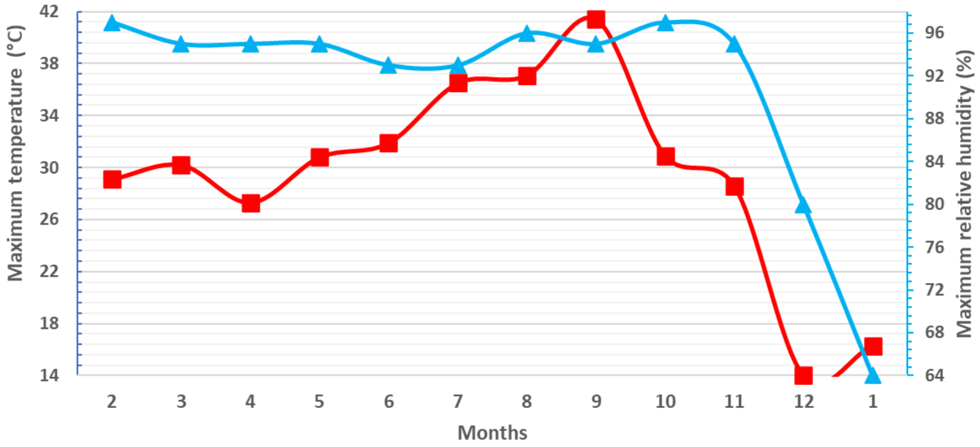

Figure 5. *Monthly trends in maximum temperature and maximum relative humidity.*

The evolution of the maximum relative humidity of the covers with two thicknesses 5 and 10 cm with the three categories of terrace covers, shows that (Table 1): Thickness 10 cm: The room with plant container cover recorded the lowest maximum relative humidity (71%) in the month of January 2022 compared with the room with pebble cover (73%) in the months of June and July 2021, the room with control cover (74%) in the month of January 2022, and lastly the room with gravel cover with a maximum relative humidity of 77% recorded in the month of June 2021. The highest maximum relative humidity was achieved in February 2021 for all cover types. The gravel-covered room recorded the highest maximum relative humidity (89%), compared with the pebble-covered room (87%). The room with control cover recorded a maximum relative humidity of 85%, and the room with plant container cover scored 84% in the months of February and March 2021. Thickness 5 cm (Table 1): The highest maximum relative humidity was achieved in February 2021 for all cover types. In fact, the room with the control cover and the gravel cover recorded the highest maximum relative humidity (85%), compared with the room with the plant container cover (84%) and the room with the pebble cover (82%). The lowest maximum relative humidity was achieved in July 2021 for all cover types. Comparing the four categories of terrace cover in July 2021. We can see that the room with the control cover recorded a rate of 74%, the room with the plant container cover scored 72%, and lastly the rooms with the gravel and pebble covers recorded a maximum relative humidity of 71%.

Table 1. *Maximum monthly relative humidity of the three covers, 5 cm and 10 cm thick covers with the control cover.*

Months	Maximum relative humidity of 5 cm thick covers (%)			Maximum relative humidity at thickness 10 cm (%)			Witness cover (%)
	Pebble	Gravel	Plant containers	Pebble	Gravel	Plant containers	
2	82	85	84	87	89	84	85
3	81	80	79	82	85	84	81
4	75	75	75	77	80	80	78
5	73	73	74	76	78	78	75
6	73	71	73	73	77	77	74
7	71	71	72	73	78	79	74
8	73	73	73	76	79	75	77

Months	Maximum relative humidity of 5 cm thick covers (%)			Maximum relative humidity at thickness 10 cm (%)			Witness cover (%)
	Pebble	Gravel	Plant containers	Pebble	Gravel	Plant containers	
9	71	74	73	78	78	76	78
10	72	76	80	81	81	77	79
11	73	78	82	85	86	79	83
12	75	78	79	79	80	79	79
1	72	75	79	79	80	71	74

From the regression equations of the maximum relative humidities of the covers at thicknesses of 5 cm (Figure 6b) and 10 cm and their relationship with the maximum ambient relative humidity, we deduce that if the maximum relative humidity of the air is 90%, then the maximum relative humidities at thicknesses of 10 cm and 5 cm are successively 80.52% and 76.75%. The value of the maximum relative humidity of the cover at thickness 10 cm compared with the ambient value (Figure 6a), shows the effect of thickness 10 cm on the decrease in relative humidity over the entire data recording period. The maximum relative humidity of the 10 cm thick cover decreased by 9.48%, and the maximum relative humidity of the 5 cm thick cover decreased by 13.25%.

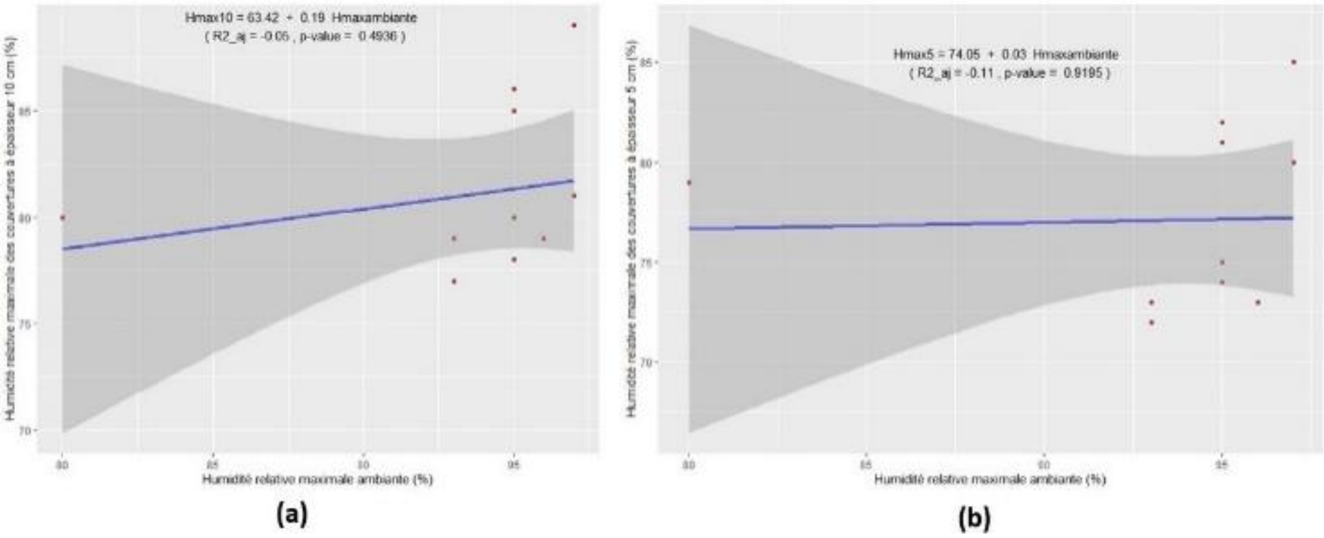

Figure 6. *Linear regression line between maximum relative humidity of 10 cm (a) and 5 cm (b) thick covers and maximum relative humidity of air.*

The linear regression equation between the maximum relative humidity of the 10 cm thick cover and the maximum relative humidity of the 5 cm thick cover with the three types of terrace cover (Figure 7), shows that if the maximum relative humidity of the 5 cm thick cover is 75%, then the maximum relative humidity of the 10 cm thick cover is 78.82%. This high value for the maximum relative humidity of the 10 cm-thick cover compared with the 5 cm-thick cover shows the effect of the 10 cm-thick cover on the increase in humidity over an entire year of climatic data recording. The rate of increase is 3.82%.

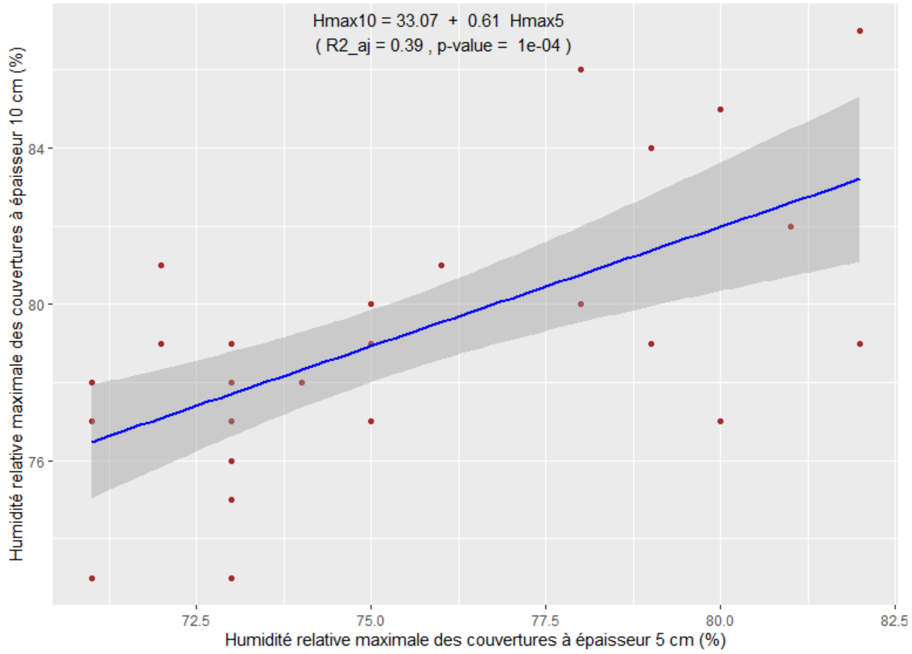

Figure 7. *Maximum relative humidity of 10 cm thick covers as a function of 5 cm thick covers.*

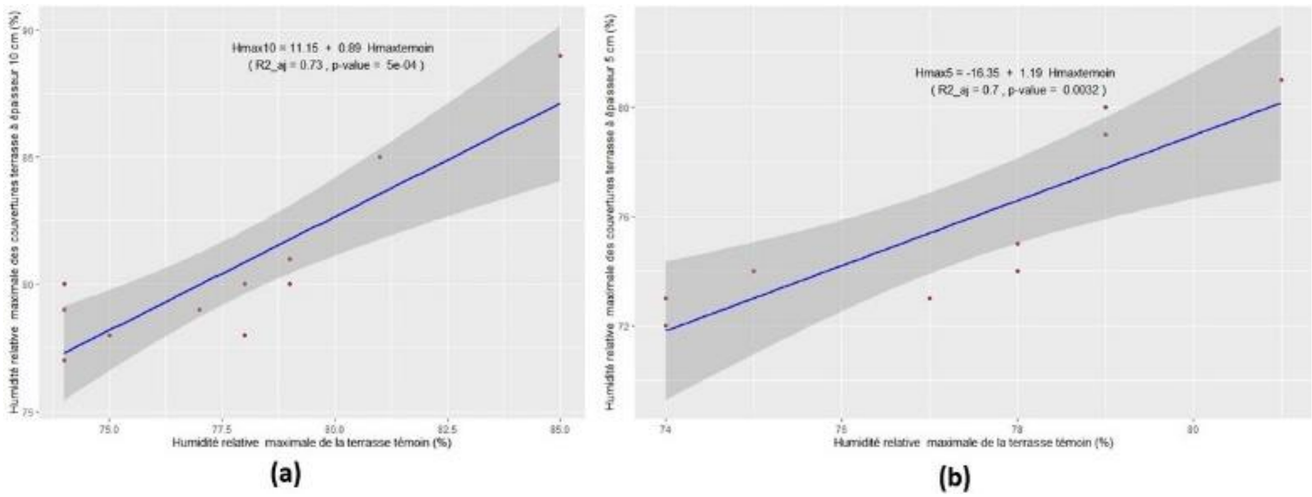

Figure 8. *The maximum relative humidity of the terrace openings has thicknesses of 10 cm (a) and 5 cm (b) depending on the maximum relative humidity of the control terrace.*

The linear regression equation between the maximum relative humidity of the 10 cm thick terrace covers and the maximum relative humidity of the control terrace (Figure 8a), shows that, when the maximum relative humidity of the control terrace is 74% and 85%, then the maximum relative humidity of the 10 cm thick terrace covers is successively 77,01% and 86,8%. From the comparison of the above values, we can deduce that the 10 cm thick terrace cover has a humidity-increases effect during the warm period (+ 3,01%). The linear regression equation between the maximum relative humidity of the 5 cm thick terrace covers and the maximum relative humidity of the control terrace (Figure 8b), shows that, when the maximum relative humidity of the control terrace is 74% and 85%, then the maximum relative humidity of the 5 cm thick terrace covers is successively 71,71% and 84,8%. From the comparison of the above values, we can deduce that the 5 cm thick terrace cover has a humidity-reducing effect during the cold period (-0,2%).

4. Conclusion

The results obtained in this period do not allow any general conclusions to be drawn on the behaviour of these variables, and it will be necessary in future to continue recording measurements for the rest of the years in order to be able to conclude in more detail the influence of the type of protective cover on humidity changes. The conclusions of this research work are as follows: The 10 cm thick terrace cover has a humidity-increases effect during the warm period (+ 3,01%). The 5 cm thick terrace cover has a humidity-reducing effect during the cold period (-0,2%). The effect of the 10 cm-thick cover on the increase in humidity over an entire year of climatic data recording: The rate of increase is 3.82%. The value of the maximum relative humidity of the cover at thickness 10 cm compared with the ambient value shows the effect of thickness 10 cm on the decrease in relative humidity over the entire data recording period. The maximum relative humidity of the 10 cm thick cover decreased by 9.48%, and the maximum relative humidity of the 5 cm thick cover decreased by 13.25%.

Abbreviations

NbS	Nature-Based Solution
RH	Relative Humidity
AW	Water Activity
St*Th10	10 cm Thick Stone (Pebble) Terrace Cover
St*Th5	5 cm Thick Stone (Pebble) Terrace Cover
Gr*Th10	10 cm Thick Gravel Terrace Cover
Gr*Th5	5 cm Thick Gravel Terrace Cover
Pl*Th10	10 cm Thick Plant Container Terrace Cover
Pl*Th5	5 cm Thick Plant Container Terrace Cover
PVC	PolyVinyl Chloride
Hmax10	Maximum relative humidity of 10 cm Thick Covers
Hmaxambiante	Maximum Relative Humidity of Air
Hmax5	Maximum Relative Humidity of 5 cm Thick Covers
Hmaxtemoin	Maximum Relative Humidity of the Control Terrace

Acknowledgments

I would like to thank the director and all the professional members of the doctoral study center at the Agronomic and Veterinary Institute Hassan II, Rabat Morocco. I'd would like to express my gratitude to my late mother, my father and my family, for supporting and encouraging me financially and mentally.

Author Contributions

Naoual Raouj: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft Writing – review & editing

Moulay Cherif Harrouni: Validation, Visualization, Writing – review & editing

Lahoussaine Baamal: Software, Validation, Visualization, Writing – review & editing

Nourredine Benaoda Tlemçani: Supervision, Validation, Visualization, Writing – review & editing

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. N. Raouj's own financing.

Data Availability

Data will be made available on request.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Técher D, Aran D, De Silva M, Claverie R, Erbrech M, Bojic C, et al. Field evaluation of the cotton-strip assay for quantifying decomposition rates in extensive green roof substrates. Urban Forestry & Urban Greening 2024; 94: 128292. https://doi.org/10.1016/j.ufug.2024.128292.

[2] Zuberbier T, Stevanovic K, Ansotegui IJ, Anto JM, Bergmann K-C, D'Amato G, et al. Green Roof Gardens – Selecting Allergy-Friendly Vegetation: A Global Allergy and Asthma Excellence Network (GA2LEN) Position Paper. The Journal of Allergy and Clinical Immunology: In Practice 2024; 12: 347–54. https://doi.org/10.1016/j.jaip.2023.10.028.

[3] Abdalazeem ME, Hassan H, Asawa T, Mahmoud H. Enhancing energy efficiency in hot climate buildings through integrated photovoltaic panels and green roofs: An experimental study. Solar Energy 2024; 270: 112419. https://doi.org/10.1016/j.solener.2024.112419

[4] Pons Fiorentin D, Martín-Gamboa M, Rafael S, Quinteiro P. Life Cycle Assessment of green roofs: A comprehensive review of methodological approaches and climate change impacts. Sustainable Production and Consumption 2024; 45: 598–611. https://doi.org/10.1016/j.spc.2024.02.004

[5] Lee E, Seo Y, Woo DK. Enhanced environmental and economic benefits of green roofs in a humid subtropical region under future climate. Ecological Engineering 2024; 201: 107221. https://doi.org/10.1016/j.ecoleng.2024.107221

[6] Muratet A, Barra M, Hardion L, Chiron F. Origins and drivers of roof plant assemblages: Designing green roofs for biodiversity conservation. Urban Forestry & Urban Greening 2024; 94: 128247. https://doi.org/10.1016/j.ufug.2024.128247

[7] Haughian SR, Lundholm JL. Mosses for minimalist green roofs: A preliminary study of the effects of rooftop exposure, species selection, and lab-grown vs. wild-harvested propagule sources. Nature-Based Solutions 2024; 5: 100119. https://doi.org/10.1016/j.nbsj.2024.100119

[8] Alizadehtazi B, Stolper J, Singh K, Montalto FA. Microclimatic implications of a large-scale green roof and high-rise redevelopment in New York City. Building and Environment 2024; 250: 111113. https://doi.org/10.1016/j.buildenv.2023.111113

[9] Lee H, He Y, Isaac ME, Roberto A. Investigating crop performance on urban green roofs using hyperspectral data. Ecological Informatics 2024; 81: 102599. https://doi.org/10.1016/j.ecoinf.2024.102599

[10] Kumar S, Ali Kubar A, Sobhi M, Cui Y, Liu W, Hu X, et al. Regulation of microclimate and shading effects of microalgal photobioreactors on rooftops: Microalgae as a promising emergent for green roof technology. Bioresource Technology 2024; 394: 130209. https://doi.org/10.1016/j.biortech.2023.130209

[11] Tiefenbacher KF. Chapter Ten - Glossary of Terms in Wafers, Waffles and Adjuncts. In: Tiefenbacher KF, editor. The Technology of Wafers and Waffles II, Academic Press; 2019, p. 325–411. https://doi.org/10.1016/B978-0-12-809437-2.00010-1

[12] Föllmi D, Corpel L, Solcerova A, Kluck J. Influence of blue-green roofs on surface and indoor temperatures over a building scale. Nature-Based Solutions 2023; 4: 100076. https://doi.org/10.1016/j.nbsj.2023.100076

[13] Flores S, Van Meerbeek K. Endangered Lomas plant communities and their potential on green roofs in Peru. Landscape and Urban Planning 2024; 247: 105061. https://doi.org/10.1016/j.landurbplan.2024.105061

[14] Heim A, Biermann B, Hicks T, Buffam I, Lundholm J. More than sedum: Colonizing weedy species can provide equivalent green roof ecosystem services. Nature-Based Solutions 2024; 5: 100101. https://doi.org/10.1016/j.nbsj.2023.100101

[15] Raouj N, Harrouni MC, Baamal L, Tlemçani NB. Sélection de végétaux adaptés aux terrasses des bâtiments en fonction de leur croissance. Revue Marocaine des Sciences Agronomiques et Vétérinaires 2023; 11: 373–9. https://doi.org/10.5281/zenodo.8289359

[16] Chen N, Deng Q, Chen Q, Wang Z. Green roof heat transfer coefficient measurement and impact of plant species and moisture. Energy and Buildings 2024; 303: 113805. https://doi.org/10.1016/j.enbuild.2023.113805