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Exploring Moisture Performance of Two Distinctive Solid Bricks under Current and Future Climate in London

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Abstract: *The increasing concerns surrounding climate change have raised apprehension about the heightened frequency and intensity of extreme weather events, globally as well as in the UK. Historic solid brick buildings, due to their construction materials and prolonged exposure to changing climate conditions, are vulnerable to the impacts of climate change, resulting in increased moisture risks that undermine their durability. Understanding the moisture behaviour of solid bricks facing climate change is therefore significant. This study aims to investigate the moisture performance, with a specific focus on moisture content, of two distinct types of bricks: handmade bricks from the 19th century and more recent – early 20th century - bricks, under current and future climate scenarios in London. The results reveal that the more recent bricks can have greater susceptibility to climate changes, providing valuable insights for the implementation of effective moisture control strategies and informed decision-making in the retrofitting of solid brick buildings in the UK.*

Keywords: *Moisture Content, Climate Change, Solid Brick, London.*

1 Introduction

Stepping into a low-carbon society, mitigation methods of controlling greenhouse gases and cutting energy consumption are the outstanding issues which will require substantial focus. The building sector accounts for a large proportion of the overall energy use and carbon emissions, contributing to over a quarter of the current carbon emissions (International Energy Agency, 2019). In the UK, the annual rate of construction of new buildings is relatively low (New Homes England, 2022), accounting for less than 1% of the existing building stock in 2022. A significant proportion of the existing building stock comprises solid masonry structures (Godwin, 2011). These buildings have poor energy performance, contributing to approximately 30% of energy consumption and 36% of carbon emissions in the housing sector of the UK (Loucari et al., 2016). These statistics confirm the urgency of retrofitting solid masonry buildings; however, any retrofit strategy needs to take into account and minimise unintended consequences, particularly those related to moisture (Marincioni et al., 2021). The climate emergency is exacerbating the risk of unintended consequences (IPCC, 2014), with an anticipation of increased intensity and frequency of extreme weather events in the future around the world, as well as in the UK (Lu et al., 2021). Historic buildings are more susceptible to climate change owing to their construction materials and longer exposure to changing climate conditions (D’Ayala & Aktas, 2016), leading to condensation and mold growth, which is not conducive to the durability and longevity of buildings. Consequently, understanding the effects of climate change is crucial when considering the retrofit of traditional solid brick buildings.

Traditional bricks can be broadly categorized into several groups, for example based on the production technique used for the bricks: older bricks are predominantly handmade, while more recent traditional bricks are produced with more controlled manufacturing processes(Gerard Lynch, 2010). Handmade bricks are crafted using traditional methods and were predominantly used before the 1900s. On the other hand, manufacturing bricks are mass-produced using modern techniques, more prevalent after the 1900s. Traditional bricks often exhibit variations in hygrothermal material properties (Xu et al., 2023), including absorption coefficient, drying coefficient, and bulk density, which can influence their moisture behaviour. The moisture performance of the historic brick walls plays an important role in building retrofit, and hygrothermal material properties are among the most influential factors for moisture performance (Zhou et al., 2018). However, hygrothermal material property data for construction materials is currently missing in the UK, and research on the moisture behaviour in the context of UK climate of these two bricks is very limited. Therefore, there is a need to fill this knowledge gap and gain a comprehensive understanding of how moisture interacts with different types of bricks under climate change situations.

This research aims to explore the moisture performance, with a specific focus on moisture content, of two distinctive types of bricks in London: a 19th century brick, handmade, and an early 20th century brick, produced with a slightly more mechanised process (here called “manufacturing” brick), under current and future climate. It is envisaged to provide valuable insights into the moisture risk assessment of traditional 19th and 20th century bricks under current and future climate scenarios. Material characterization, climate data analysis, and hygrothermal simulations are combined for a comprehensive understanding of the moisture content of the bricks, which contribute to the development of effective moisture control strategies and building retrofit decision-making, ensuring the long-term durability, energy efficiency of solid brick buildings in the UK.

2 Methodology

2.1 Brick Samples and Material Properties Characterisation

Figure 1 Brick A

Figure 2 Brick B

In this study, two groups of bricks were collected and analysed, as illustrated in Figure 1-2. Figure 1 represents a collection of 21 handmade (Brick A) bricks obtained from a 19th century wall located in London. These bricks are coloured yellow, and their shapes, size and texture show slight variations from one another. In contrast, Figure 2 shows 40 red manufacturing bricks (Brick B) sourced from a reclaimed building site in London, constructed in the 1910s. These bricks display a more uniform shape and size. The experiments focused on measuring two important hygrothermal material properties: absorption coefficient and capillary saturation content, for both groups of bricks. The water absorption coefficient was performed according to BS EN ISO 15148 (2002) and capillary saturation content was measured after the sample reached capillary saturation. Then, the average value of each material property from two groups of bricks were calculated and used for the selection of the material files used for subsequent hygrothermal simulations.

2.2 Hygrothermal Simulation

The hygrothermal simulation for the two groups of brick samples were performed in Delphin 6.1.5. The weather files used in this study can be divided into reference climate (current) and future prediction climates, all provided by Lu et al. (2021), using weather observations from the London Weather Centre (LWC) and future prediction data from UKCP18. For future predictions, the years 2040 and 2080 were selected to represent near and far future respectively. In order to explore the impact of rain penetration on the moisture content of different bricks, the years with 50th and 90th percentile rainfall were selected which can be more representative based on BS EN 15026 (2007), shown in figure 3.

New material categories for Brick A and Brick B were created in material database in Delphin based on one category named “old building brick”, whose material properties is quite similar to historic bricks in the UK. The absorption coefficient and capillary saturation content obtained from laboratory experiments for these two types of bricks were incorporated into the respective categories. Subsequently, 1D simulations were conducted on each brick category using six analyzed climate files. Finally, the results regarding the total moisture content of the brick wall were acquired through simulation

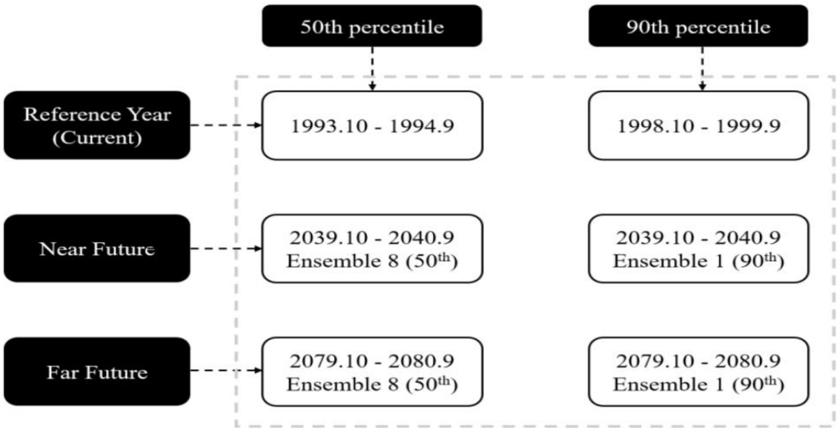

Figure 3 Climate files

3 Results and discussion

Table 1 Hygrothermal material property results

	Absorption coefficient kg/m^2·s$^{1/2}$	Capillary saturation content m^3/m^3
Brick A	0.4644	0.2912
Brick B	0.0632	0.2436

Table 2 Climate file information (Lu et al., 2021)

		1993 (50th)	2040 (50th)	2080 (50th)	1999 (90th)	2040 (90th)	2080 (90th)
Air temperature [°C]	Max	30.9	34.6	44.7	31.9	32.7	37.0
	Min	-4	0	0.8	-1.3	-2.2	-3.1
	Average	11.5	14.5	16.8	12.4	13.5	15.5
Relative Humidity [%]	Max	100	99.0	99.0	96.9	99.0	99.0
	Min	25.3	5.0	5.0	19.2	19.0	23.0
	Average	70.1	67.6	63.7	70.3	73.4	72.5

Table 1 shows the experimental results of hygrothermal material properties for Brick A and Brick B. The absorption coefficient and capillary saturation content for Brick A are both greater than Brick B, indicating that Brick A is more prone to moisture absorption and has a higher moisture storage capacity compared to Brick B.

The temperature and relative humidity data of 6 climate files are presented in table 2. The average yearly air temperature increases for both 50th percentiles and 90th percentiles from the current year to 2080. The ranges of the future temperatures also become larger for both percentiles. The weather becomes hotter in summer, especially in the year 2080, which has the highest temperature of nearly 45 °C in the 50th and 37 °C in the 90th percentiles. Moreover, the amounts of normal rain are higher than that in current years for both percentiles. Figure 4 about wind-driven rain (from Lu et al. 2021) has indicated that the winter would be wetter and the summer would be dryer in future.

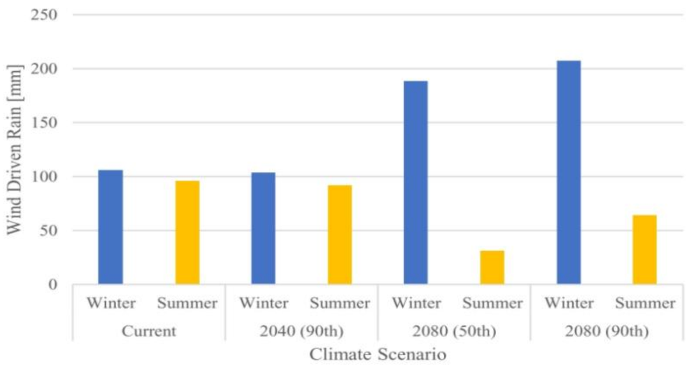

Figure 5 Distribution of the wind-driven rain (Lu et al., 2021)

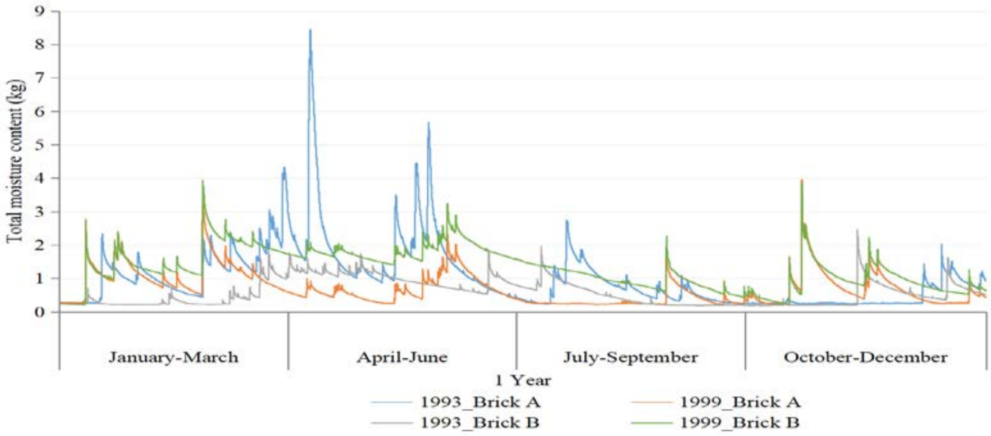

Figure 6 Total moisture content fluctuation of Brick A and Brick B under current climate files

Table 3 Total moisture content for Brick A and Brick B under 6 climate files

Brick A (kg)	1993 (50th)	2040 (50th)	2080 (50th)	1999 (90th)	2040 (90th)	2080 (90th)
Ave	1.013	0.705	0.891	0.694	1.013	1.297
Min	0.230	0.231	0.218	0.213	0.230	0.229
Max	8.447	5.072	8.540	3.958	8.447	5.335
Min to Max range	8.217	4.841	8.322	3.744	8.217	5.106
Brick B (kg)	1993 (50th)	2040 (50th)	2080 (50th)	1999 (90th)	2040 (90th)	2080 (90th)
Ave	0.581	1.598	3.701	1.296	3.646	4.615
Min	0.187	0.217	0.226	0.222	0.221	0.216
Max	2.455	6.195	14.214	3.934	10.612	10.648
Min to Max range	2.268	5.978	13.989	3.713	10.391	10.431

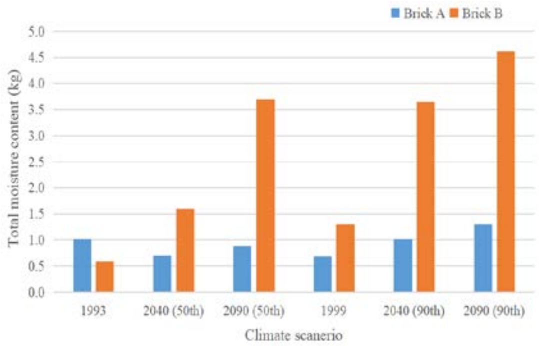

Figure 7 Average of total moisture content

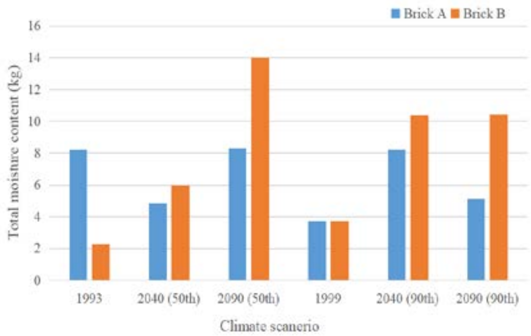

Figure 8 Min-Max range of total moisture content

Figure 6 shows the examples of one-year fluctuation of total moisture content of Brick A and Brick B under two current climate files with average rainfall and near-extreme rainfall. Initially, the analysis included 3 years of data. However, it was observed the results showed a regular pattern of change in each. Consequently, to simplify the analysis, a single year of data was selected for further analysis. Table 2 displays the total moisture content results of Brick A and Brick B under six climate files. For each set of data, the average value, maximum value, minimum value, and range difference between the min and max are calculated individually. Based on Figure 7-8, it is observed that for brick A, the average of moisture content will relatively decrease with 50^{th} percentiles future climate and a slightly rise with 90^{th} percentiles future climate. On the other hand, for Brick B, the moisture content will significantly increase in the future climate, regardless of whether it is the 50th percentiles or the 90th percentiles. Additionally, it is anticipated that the variation of moisture content for Brick B will progressively increase in the future compared to Brick A, particularly with 50th percentiles climate files. These results suggest that Brick B is more susceptible to changes in temperature and humidity in future weather conditions. The substantial increase in moisture content for Brick B compared to Brick A could be determined by the differences in material properties, making Brick B more responsive to environmental changes.

This is an initial attempt to delve into the differences of traditional bricks in the UK; some areas of further development are outlined below. Firstly, the current study hasn't considered the distribution of material properties for analysis. During the experiment, it was found that different bricks from one wall have great variability in their hygrothermal material properties (Xu et al., 2023), which highlights the need to account for material property distributions in future simulations. Incorporating this variability can provide a more comprehensive understanding of the moisture behaviour and performance of the bricks, allowing for more accurate predictions and assessment. Secondly, the results reveal that different brick types have very different moisture performance in response to climate changes which will lead to different moisture risks. Therefore, different strategies need to be taken into practice for different brick wall types when considering historic brick building retrofit (Zhou et al., 2022). In addition, to better understand the potential risks and assess moisture-related damage, it would be beneficial to examine the moisture content at the critical surfaces and interfaces that are likely to experience moisture-related damage. This can help assess potential moisture-related risks, such as frost damage and mould growth risk, and inform mitigation measures. At the same time, the impact of mortar and insulation also need to be considered. These elements can significantly influence the moisture transport and the overall hygrothermal behavior of the wall.

4 Conclusion

This study focused on the characterisation and analysis of two distinct types of bricks found in London. The absorption coefficient and capillary saturation content of these bricks were determined through experimental testing. Subsequently, 1D simulations were conducted using Delphin to assess the total moisture content within the wall under current, near future, and far future climate scenarios. The findings of this study indicate that in future climates, London is projected to experience significantly higher temperatures and relative humidity levels. Winters will become wetter while summers will become drier in the future. These climate changes have implications for the moisture performance of the tested bricks. The early 20th century bricks are more susceptible to the effects of climate change compared to handmade bricks from 19th century. It shows a higher sensitivity to variations in temperature and humidity, leading to increased moisture content within the wall. These results can be a good starting point for understanding moisture performance of solid brick buildings in London and filling the gap of much needed hygrothermal material data.

In future studies, the variability of material properties can be considered in simulations and more hygrothermal material properties can be tested and then imported into simulation, enhancing the accuracy of the simulations and improve the understanding of moisture dynamics within solid brick walls, considering all potential moisture risks. These suggested improvements would provide valuable insights into the hygrothermal behaviour of brick walls, enabling more informed decision-making for solid wall retrofit in London in response to climate changes.

Reference

BSI BS EN 15148 (2002). *Hygrothermal performance of building material and products-Determination of water absorption coefficient by partial immersion.*

BSI BS EN 15026 (2007). *Hygrothermal performance of building components and building elements-Assessment of moisture transfer by numerical simulation.*

D'Ayala, D., & Aktas, Y. D. (2016). *Moisture dynamics in the masonry fabric of historic buildings subjected to wind-driven rain and flooding*. Building and Environment, 104, 208–220.

IPCC (2014), *Climate Change 2014: Impacts, Adaptation and Vulnerability*, Cambridge University Press, Cambridge.

Gerard Lynch. (2010). *The History of Gauged Brickwork*.

Godwin, P. J. (2011). *Building Conservation and Sustainability in the United Kingdom*. Procedia Engineering, 20, 12–21.

International Energy Agency. (2019). *CO2 emissions from fuel combustion 2019*.

Loucari, C., Taylor, J., Raslan, R., Oikonomou, E., & Mavrogianni, A. (2016). *Retrofit solutions for solid wall dwellings in England: The impact of uncertainty upon the energy performance gap*. Building Services Engineering Research and Technology, 37(5), 614–634.

Lu, J., Marincioni, V., Orr, S. A., & Altamirano-Medina, H. (2021). *Climate resilience of internally-insulated historic masonry assemblies: Comparison of moisture risk under current and future climate scenarios*. Minerals, 11(3), 1–14.

Marincioni, V., Gori, V., Hansen, E. J. de P., Herrera-Avellanosa, D., Mauri, S., Giancola, E., Egusquiza, A., Buda, A., Leonardi, E., & Rieser, A. (2021). *How can scientific literature support decision-making in the renovation of historic buildings? An evidence-based approach for improving the performance of walls*. Sustainability (Switzerland), 13 (4), 1–21.

New Homes England 2021-22 housebuilding statistics revealed - GOV.UK., from https://www.gov.uk/government/news/new-homes-england-2021-22-housebuilding-statistics-revealed.

Xu, B., Cambray, T., Marincioni, V., & Mavrogianni, A. (2023). *Exploring the variability of hygrothermal material properties in historic bricks in London.* NSB 2023.

Zhou, X., Carmeliet, J., & Derome, D. (2018). *Influence of envelope properties on interior insulation solutions for masonry walls*. Building and Environment, 135, 246–256.

Zhou, X., Derome, D., & Carmeliet, J. (2022). *Analysis of moisture risk in internally insulated masonry walls*. Building and Environment, 212.