Vernacular Materials for Thermal Comfort

Utilizing Dulmera Sandstone Tiles in Rajasthan's Arid Climate

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ABSTRACT

This study proposes Dulmera sandstone cooling tiles as a novel solution to the prevalent heat absorption problems in building construction, particularly in hot climates, such as that of Bikaner, Rajasthan. The objective is to enhance building energy efficiency and indoor comfort while promoting sustainable practices. The development of Dulmera slim tiles uses the natural cooling properties of Dulmera sandstone, with research focusing on its heat absorption and emission characteristics. This approach integrates traditional knowledge with modern manufacturing techniques, addressing heat-related building challenges. The findings indicate that these tiles significantly reduce heat absorption and emission, leading to decreased reliance on energy-intensive cooling systems, lower electricity consumption, and reduced greenhouse gas emissions. Additionally, the tiles enhance indoor comfort, boost occupant well-being, and improve productivity. The innovation's distinctiveness stems from its incorporation of locally available materials and state-of-the-art manufacturing methodologies, providing a culturally sensitive and sustainable solution that safeguards Rajasthan's architectural heritage. Consequently, Dulmera sandstone cooling tiles emerge as a valuable and scalable solution for analogous climates worldwide, fostering resilience and environmental consciousness in the built environment.

Keywords-cooling tiles; resilient; energy conservation; climate; Rajasthan

I. INTRODUCTION

In the dry, desert-like areas of western Rajasthan, Bikaner exemplifies the region's distinctive architectural character and its arid climate. The usage of Dulmera sandstone cooling slim tiles presents an innovative approach to preserving traditional heritage while addressing contemporary climate-related challenges. This study examines the manner in which the inherent thermal properties of Dulmera sandstone contribute to the reduction of heat accumulation in buildings, thereby providing an eco-friendly alternative to conventional cooling methods [1]. The integration of traditional materials, such as Dulmera sandstone, into contemporary building practices not only enhances indoor comfort, but also contributes to global sustainability objectives by reducing the reliance on energy-consuming cooling systems. The study analyzes the implementation of these tiles in modern building practices, with the objective of addressing the intense heat waves that are characteristic of Bikaner's summers [2]. The research area evaluates the comparative advantages of Dulmera sandstone cooling slim tiles over conventional cooling systems with respect to energy efficiency and indoor climate control. The study further explores how these tiles contribute to the conservation of Rajasthan's architectural heritage while addressing contemporary climate challenges. Additionally, it examines how this innovation promotes sustainable building practices and reduces carbon footprints. Finally, the study considers the potential for replicating the successful application of these tiles in other similar climatic conditions, identifying the key factors that could influence their scalability [3]. This introduction establishes a foundation for comprehending how Dulmera sandstone cooling slim tiles embody a significant advancement in safeguarding cultural heritage while enhancing resilience to climate extremes in Bikaner and other regions.

II. LITERATURE REVIEW

The invention of Dulmera sandstone cooling slim tiles has been developed to address the critical challenge of mitigating extreme heat conditions in Bikaner, Rajasthan, and similar hot climates [4]. Conventional building materials have been observed to contribute to elevated heat absorption, exacerbating urban heat islands and leading to augmented energy consumption for cooling purposes. This disclosure pertains to construction materials, particularly a cooling tile designed to reduce indoor temperatures by obstructing the incoming sunlight. By harnessing the inherent cooling properties of the local Dulmera sandstone, these tiles effectively mitigate heat absorption in buildings, thus promoting cooler indoor environments while reducing reliance on energy-intensive cooling systems [5, 6]. This innovation enhances occupant comfort and well-being while supporting sustainable building practices by using indigenous materials and reducing greenhouse gas emissions. This proactive approach to preserving architectural heritage while addressing the environmental needs of contemporary construction in hot and dry regions is a significant contribution to the field [7].

A. Chemical Composition of Cooling Tiles

Dulmera slim cooling tiles are typically manufactured with a standard thickness of 12 mm, which can be reduced to 10 mm for tiles of 300 mm × 300 mm or smaller [5]. Table I shows the properties of the tiles.

TABLE I. CHEMICAL AND PHYSICAL PROPERTIES OF DULMERA SLIM COOLING TILES

Electric conductivity	**719.0 µS/cm**
pH	7.8
$CaCO_3$	14.00%
Total Dissolved Solids (TDS)	361.0 mg/l
NaCl	1.40%
Modulus of Rupture (MOR)	83.00 kg/cm^2
Loss of Ignition	3.00%
SiO_2	46.00%
SO_3	0.10%
Na_2O	1.20%
P_2O_5	0.10%

These properties are indicative of the tile's capacity for electrical conductivity, pH balance, mineral content, strength, and chemical composition, which are essential for understanding its suitability in various construction applications, especially in hot and arid climates, like that of Bikaner, Rajasthan [8].

B. Novelty of Material

The introduction of Dulmera sandstone slim tiles marks a significant advancement in the field of construction materials, offering distinct advantages over the conventional building materials:

- These tiles are notable for their inherent capacity to regulate temperature. They are capable of absorbing and releasing heat, thereby stabilizing indoor temperatures, which is a key benefit in terms of occupant comfort and energy efficiency. This property stands in contrast to traditional materials that tend to retain heat, contributing to elevated indoor temperatures [9, 10].
- Local sourcing of the Dulmera sandstone contributes to its sustainability, aligning with the principles of environmental responsibility and resource conservation. The tiles are made from locally quarried Dulmera sandstone, which supports sustainable practices by minimizing transportation-related carbon emissions [11].
- Tailored Engineering: Through precise chemical analysis and material testing, Dulmera sandstone slim tiles are engineered to optimize thermal conductivity, specific heat capacity, and surface properties. This customization ensures superior performance in hot climates, like that of Bikaner, Rajasthan, enhancing their effectiveness in heat reduction [12].
- The tiles' versatility and aesthetic appeal are noteworthy. Beyond their functional benefits, these tiles offer a sleek, modern aesthetic suitable for a variety of architectural styles. Their slim profile facilitates an easy installation in both new constructions and renovations, adding versatility to their application [13, 14].
- Enhanced comfort and energy efficiency are further advantages of Dulmera sandstone slim tiles. By helping to maintain cooler indoor temperatures naturally, they improve occupant comfort and reduce reliance on mechanical cooling systems [15]. This contributes to energy efficiency, potential cost savings, and environmental benefits over time [16, 17].
- The cultural significance is highlighted by the use of locally sourced Dulmera sandstone, contributing to the preservation of regional architectural heritage, making them not only more functional, but also culturally important in contemporary building practices [17].

In summary, the distinctive characteristics of Dulmera sandstone slim tiles are derived from their innate cooling properties, eco-friendly origins, customized designs aimed at enhancing performance, adaptable styles, and cultural significance. [18]. It is therefore evident that these characteristics position them as innovative solutions to the challenges of heat mitigation in hot climate regions.

III. METHODOLOGY

The methodology employed in the development of Dulmera sandstone slim tiles is displayed in Table II and Figure 1, emphasizing the systematic approach undertaken to address the challenges posed by the heat exposure in high-temperature environments.

TABLE II. METHODOLOGY FOR DEVELOPMENT

Steps	**Description**
Step 1: Material Selection	Locally source Dulmera sandstone chosen for natural cooling properties and regional suitability.
Step 2: Chemical Analysis	Comprehensive analysis to determine the composition of dulmera stone (SiO2, CaCO3, NaCl, etc.) and its suitability for custom engineering.
Step 3: Engineering & Design	Customization of tile properties (thermal conductivity, specific heat capacity) through iterative design and testing.
Step 4: Manufacturing	Innovative techniques to produce slim tiles (reduced to 10 mm thickness) while maintaining structural integrity and cooling efficiency.
Step 5: Performance Testing	Rigorous evaluation of tiles in simulated and real-world conditions for heat absorption, thermal regulation, durability (MOR), and environmental impact.
Step 6: Application and Versatility	Consideration of aesthetic appeal and ease of installation in various architectural styles, ensuring suitability for new and retrofit projects.
Step 7: Sustainability	Focus on sustainable practices, from sourcing locally to reducing environmental impact.
Step 8: Cultural Integration	Incorporating the cultural importance of Dulmera sandstone to preserve the regional architectural heritage while adapting to modern construction methods.

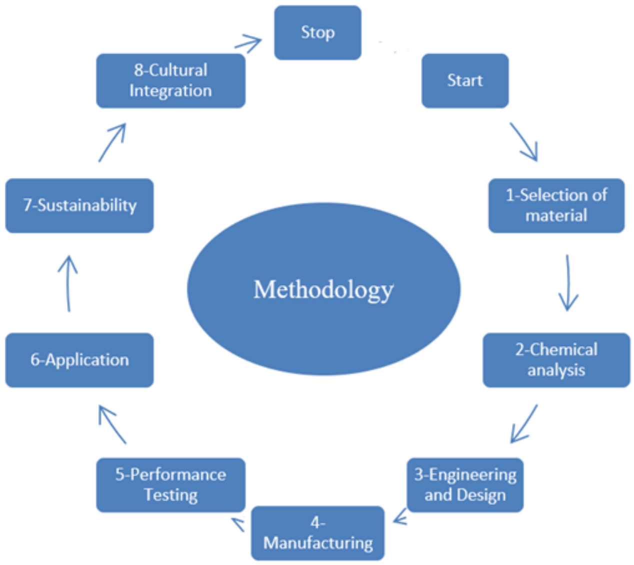

Fig. 1. Methodology involved in innovation.

A. Application of Dulmera Sandstone in Natural Form

The plan and accompanying sketches shown in Figure 2, provide a demonstration of the usage of the Dulmera stone in the facades, railings, and arches of traditional havelis in western Rajasthan. Renowned for its sustainability and capacity to provide thermal cooling, Dulmera stone is being adapted into slim tiles, representing an innovation that aims to enhance the durability and eco-friendliness of modern construction methods.

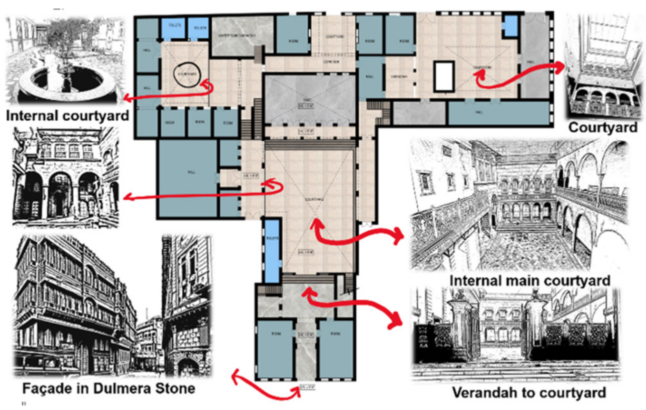

Fig. 2. Plan of a Haveli in Bikaner , Rajasthan with application of dulmera stone on facade.

IV. RESULT AND DISCUSSION

A. Objectives of the Study

A primary objective of this study is to mitigate the heat absorption of building surfaces, particularly in hot climates. This objective is achieved by employing a high concentration of SiO_2, which reflects a substantial portion of the incident solar radiation while permitting a minimal amount of sunlight to be transmitted. This process generates a cooling effect. The present analysis introduces a cooling tile designed to effectively reduce heat absorption and decrease indoor temperatures. This is achieved through its high reflectivity, which minimizes the solar heat gain on building surfaces. This feature enhances energy efficiency by reducing the demand for cooling, thereby improving indoor comfort and promoting sustainable construction practices. Furthermore, the tile's durability, UV resistance, and adaptability for various architectural uses support its role in creating cooler and environmentally friendly built environments. In Figure 3, the composition of the cooling tile is described, comprising a layer of calcium carbonate ($CaCO_3$) ranging from 10% to 20% by weight, sodium chloride (NaCl) ranging from 0.5% to 2% by weight, and silicon dioxide (SiO_2) ranging from 40% to 50% by weight. The Dulmera cooling tile also contains phosphorus pentoxide (P_2O_5) ranging from 0.10% to 1% by weight, sulfur trioxide (SO_3) ranging from 0.10% to 1% by weight, and sodium oxide (Na_2O) ranging from 0.10% to 1% by weight. The scattering of the incoming sunlight, a phenomenon known as the Fresnel effect, redistributes light in different directions, hence reducing the intensity of the direct sunlight passing through the material. This phenomenon, known as the scattering effect, contributes to the cooling process by diffusing the light and thereby reducing the amount of direct solar heat gain. The refractive index of the silicon dioxide (SiO_2) is approximately 1.46, which results in a significant bending of the light rays as they transition from air into the SiO_2 layer. The refractive index is a quantitative metric that quantifies the degree to which the light slows down and changes direction upon entering a material.

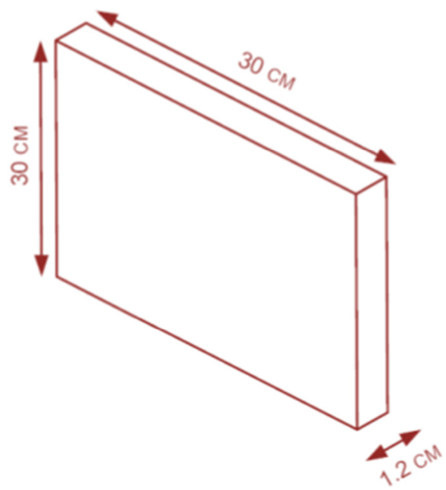

Fig. 3. View of the cooling tile.

The bending of the light rays can be described by Snell's Law, which states:

$$n_1 sin\theta_1 = n_2 sin\theta_2$$

where n_1 and n_2 are the respective refractive indices of the media (air and SiO_2) and θ_1 and θ_2 are the angles of incidence and refraction, respectively. Due to the high refractive index of SiO2, the angle of refraction (θ_2) is smaller than the angle of incidence (θ_1), causing the light to bend towards the surface. The behavior of the sunlight interacting with a material can be described in terms of reflectance, absorbance, and transmittance. These properties are defined as the proportion of the incident light that is reflected, absorbed, and transmitted, respectively. Reflectance (R) is defined as the ratio of the reflected light to the incident light, absorbance (A) is the ratio of the absorbed light to the incident light, and transmittance (T) is the ratio of the transmitted light to the incident light. The relationship between these properties for a material is given by: $R+A+T=1$, where R, A, and T are fractions that can be expressed as percentages by multiplying by 100. In Figure 4, a wall section is presented that exhibits multiple cooling Dulmera tiles. These tiles are defined by their elevated silica content and are endowed with a UV-resistant coating that serves to augment the sunlight reflection and curtail heat absorption [19]. These tiles have been found to function effectively as wall cladding and can be arranged in a manner that aligns with the roof tiles, therefore ensuring consistent thermal performance throughout the building envelope [20]. The cooling tile, composed of Dulmera stone, is coated with a resilient UV-resistant material, such as titanium dioxide (TiO_2), or zinc oxide (ZnO), thereby safeguarding the silica layer from UV-induced deterioration. This protective coating contributes to the longevity of the cooling tile by preserving its reflective efficiency over time [21]. Furthermore, the cooling tile is designed with customizable edge profiles that are meticulously crafted to align with the architectural curvature of diverse structures [22].

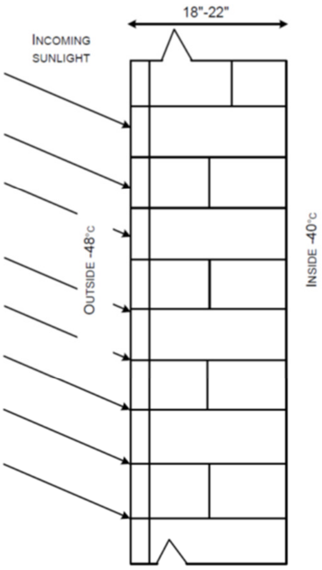

Fig. 4. The configuration of the cooling tile intending to deflect the sun's rays, reducing the overall temperature.

This study introduces a cooling tile designed with high reflectivity, capable of reflecting up to 70% of incident sunlight away from the building it covers. By reducing the absorption of solar radiation by the building's surface, the tile contributes to a reduction in exterior temperatures, hence fostering a more temperate indoor environment [23, 24]. The Dulmera sandstone tiles have been shown to reflect more sunlight and significantly reduce heat absorption. This reduction in heat absorption leads to a decrease in the cooling load on air conditioning and other cooling systems, resulting in reduced energy consumption to maintain comfortable indoor temperatures, leading to considerable savings [25, 26].

B. Conducted Experiment for Measurement of Temperature during Peak Summer

As evidenced in Table III, a comprehensive temperature analysis was conducted in April and May of 2023. This analysis was carried out in a Haveli, with temperature measurements being taken both inside and outside the building. Figure 5 presents the temperature and humidity analysis for May 31, 2023, and June 1, 2023, while Table IV offers a quantitative assessment of the thermal sensation during day and night hours, categorized according to the comfort zone.

TABLE III. TEMPERATURE ANALYSIS

April 2023					
Date	Time	Stone wall surface temp. outside Haveli	Wall surface temp. Inside Haveli	Dry bulb Temp. outside the Haveli	Dry bulb Temp. inside the Haveli
29/04/2023	1:00 pm	31 °C	29 °C	34 °C	28.5 °C
28/04/2023	1:00 pm	34 °C	33 °C	37 °C	31 °C
27/04/2023	12:55 pm	34.5 °C	32 °C	37 °C	31.5 °C
26/04/2023	1:00 pm	37 °C	35.5 °C	39 °C	34 °C
25/04/2023	1:10 pm	35 °C	34 °C	38 °C	33 °C
24/04/2023	1:50 pm	34 °C	32 °C	36 °C	31 °C
23/04/2023	12:40 pm	32 °C	30 °C	35 °C	29.5 °C
22/04/2023	12:50 pm	34 °C	32 °C	38 °C	33 °C
21/04/2023	12:50 pm	33 °C	31 °C	37 °C	31 °C
20/04/2023	1:00 pm	34.5 °C	32 °C	36 °C	30 °C
May 2023					
15/05/2023	1:00 pm	40 °C	37 °C	42 °C	36.5 °C
14/05/2023	12:55 pm	41 °C	39 °C	44 °C	38 °C
13/05/2023	12:59 pm	42.5 °C	39.5 °C	45 °C	38.5 °C
12/05/2023	1:00 pm	42 °C	39 °C	45 °C	39 °C
11/05/2023	1:00 pm	41 °C	38.5 °C	44 °C	38.5 °C
10/05/2023	1:00 pm	38 °C	35 °C	41 °C	36 °C
09/05/2023	12:30 pm	37 °C	34 °C	40 °C	35.5 °C
08/05/2023	12:50 pm	37.5 °C	35 °C	40 °C	35. °C
07/05/2023	12:50 pm	37 °C	34 °C	40 °C	36 °C
06/05/2023	1:00 pm	36 °C	33 °C	39 °C	35 °C

TABLE IV. DAY/NIGHT THERMAL SENSATION BASED ON COMFORT ZONE (BIKANER OLD CITY)

Bikaner	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min (°C)	8	11	16	23	27	28	28	27	25	21	14	9
Max (°C)	20	24	30	37	40	39	35	34	34	33	28	22
Avg. (°C)	13.5	16.9	22.5	29.2	32.7	33	29.9	28.7	27.8	25.4	20.5	15.4
RH Avg. (%)	75.9	66.6	52.5	44.4	41.7	56.6	79.6	81.8	82	70	70.3	76.5
RH min (%)	44.9	37.5	24.2	15.6	14.9	30	40.2	60.3	55.4	39.7	36.3	49.4
RH max (%)	100	94.4	87.5	84.9	74.1	95.1	96.2	95.5	98.2	90.4	93.6	97.2
HI (min) (°C)	7	11	16	24	29	35	35	32	25	22	14	8
HI max (°C)	19	23	28	35	38	41	37	42	40	34	27	22

DATA LOGGER SamplingRate:3600

Start mode: Instant
Record mode: Cycle
LED flash interval:10
Temp. high alarm:50
Temp. low alarm:10
RH high alarm:80
RH low alarm:20
Alarm out: Disable
LED1 flash: Disable
LED2 flash: Enable
Date Format:0
Channel:2
TEMP. Unit: Celsius
DataNumber:32
StartTime:2023-05-31 12:25:20

EndTime:2023-06-01 19:25:20

T1Max(5):30.7
T1Min(18):28.0
T1Average:29.6
RHMax(16):57.8
RHMin(4):41.2
RHAverage:48.6

NO	Datetime	RH	TI
0	5/31/2023 12:25	45.5	29.8
1	5/31/2023 13:25	42.8	29.9
2	5/31/2023 14:25	41.7	30.1
3	5/31/2023 15:25	41.8	30.4
4	5/31/2023 16:25	41.2	30.6
5	5/31/2023 17:25	41.3	30.7
6	5/31/2023 18:25	42	30.6
7	5/31/2023 19:25	42.5	30.5
8	5/31/2023 20:25	43.4	30.4
9	5/31/2023 21:25	44.5	30.3
10	5/31/2023 22:25	45.6	30.2
11	5/31/2023 23:25	46.1	30.1
12	6/1/2023 0:25	45.2	30
13	6/1/2023 1:25	45.7	29.9
14	6/1/2023 2:25	51.6	29
15	6/1/2023 3:25 55.4	28.5	
16	6/1/2023 4:25	57.8	28.3
17	6/1/2023 5:25	55.6	28.1
18	6/1/2023 6:25	54.7	28
19	6/1/2023 7:25	54.2	28
20	6/1/2023 8:25	54.6	28.1
21	6/1/2023 9:25	54.2	28.6
22	6/1/2023 10:25	54.5	29
23	6/1/2023 11:25	53.9	29.3
24	6/1/2023 12:25	50.2	29.5
25	6/1/2023 13:25	49.1	29.7
26	6/1/2023 14:25	48.9	30
27	6/1/2023 15:25	50.7	30
28	6/1/2023 16:25	51.9	30
29	6/1/2023 17:25	51.9	29.9
30	6/1/2023 18:25	48.7	29.7
31	6/1/2023 19:25	49.5	29.6

Fig. 5. Temperature and humidity analysis for 31 May 2023 and 1 June 2023.

C. Results

When the Bikaner heat index is compared to the comfort zone (22°C to 27°C), it is evident that both daytime and nighttime temperatures during December and January result in cold stress.

- December and January: Both day and night induce cold stress due to temperatures falling outside the comfort zone (22°C to 27°C).
- Mid-February to mid-March: During this period, daytime temperatures remain within the comfortable range, while nighttime temperatures persist below the comfort zone, extending into March.
- April: Nighttime temperatures then become consistent with the established comfort zone.
- Mid-March to mid-November: During this period, daytime temperatures deviate from the established comfort range.
- Early-May to late August: Nighttime temperatures extend beyond the comfort range, inducing heat stress for both day and night.

These observations are derived from a comprehensive analysis of Bikaner's climatic conditions and the corresponding experimental data.

V. CONCLUSIONS

In summary, the cooling tile, crafted from Dulmera sandstone, which is abundant in silicon dioxide (SiO_2) and other reflective components, effectively reduces the incoming solar radiation. This results in a significant temperature decrease of 8-10 degrees Celsius compared to traditional materials. This enhancement of the indoor thermal comfort, achieved by minimizing the heat transfer, stands to reduce the reliance on energy-consuming cooling systems, thus fostering sustainability. The tile's versatility in applications, such as roofs, walls, and facades, coupled with its enduring reflective properties and durability even in harsh environments, makes it a practical choice. The tile's carved front surface optimizes sunlight reflection, a feature that is particularly beneficial in heritage buildings and modern constructions alike. The promotion of Dulmera sandstone in Bikaner, Rajasthan, where it is abundant, underscores its suitability for the region's hot and dry climate, contributing to sustainable architectural practices. The recent presentation unveils a novel cooling tile crafted from Dulmera stone, a material well-suited for diverse building surfaces, including roofs, walls, and facades. This enhancement of architectural flexibility and construction options is further ensured by the tile's unique chemical composition, which guarantees thermal comfort within the structure. In climates characterized by high temperatures, the efficacy of insulation plays a significant role. Inadequately insulated buildings experience difficulties in maintaining comfortable indoor temperatures, leading to increased energy consumption for cooling purposes. A significant challenge arises when attempting to employ insulation materials intended for temperate climates in hotter regions. The failure of these materials to withstand elevated temperatures, in conjunction with their suboptimal thermal efficiency under such conditions, renders them ill-suited for use in more tropical climates. Consequently, air conditioning becomes essential in hot climates, significantly contributing to a building's overall energy consumption. This phenomenon not only leads to escalating operational costs, but also amplifies the carbon footprint of the buildings, thereby exacerbating their environmental impact. The usage of advanced solutions, such as Dulmera sandstone cooling tiles, which demonstrably decrease heat absorption and reduce reliance on energy-consuming cooling systems, offers a sustainable approach to addressing the challenges posed by hot climates.

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