

Cool Roof Impact on Thermal Comfort and Temperature Range Effect on Energy Consumption in Tropical Climates

Mamadou Aliou II Diallo^{1,2*}, Mamadou Yaya Balde^{3,4}, Mamadou Oury 2 Diallo³,
Mohammed Ahachad^{1,5}, Zaid Romani⁶

¹MaSEEL, FST of Tangier, Abdelmalek Essaâdi University, Tangier, Morocco

²Department of Physics, University Julius Nyerere of Kankan, Kankan, Guinea

³Institut de recherche en environnement de Guinée (IREG), Conakry, Guinea

⁴Laboratoire de chimie-physique de l'Université Gamal Abdel Nasser de Conakry (Guinée), Conakry, Guinea

⁵School of Architecture, Planning and Design (SAP + D), Benguerir, Morocco

⁶Landscape (LaBEL), National School of Architecture of Tetouan, Tetouan, Morocco

Email: *aliuousombili@gmail.com, baldez201073@gmail.com, jallowmohamad@gmail.com, ahachad_med@yahoo.fr, romanizaid@gmail.com

How to cite this paper: Diallo, M.A.II., Balde, M.Y., Diallo, M.O2., Ahachad, M. and Romani, Z. (2026) Cool Roof Impact on Thermal Comfort and Temperature Range Effect on Energy Consumption in Tropical Climates. *Journal of Materials Science and Chemical Engineering*, 14, 26-35. <https://doi.org/10.4236/msce.2026.145003>

Received: November 29, 2025

Accepted: May 24, 2026

Published: May 27, 2026

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Abstract

This research examines the impact of cool roofs on thermal comfort and energy consumption in Conakry, Guinea, which has a hot and humid tropical climate. A dynamic simulation using the TRNSYS-CONTAM coupling was performed on a typical residential building. Results from the reference building showed high indoor temperatures, with a 57% discomfort rate in the living room zone. Applying a cool roof with an absorption coefficient of 0.3 reduced the roof surface temperature by 15°C. The living room operative temperature also decreased by 2.4°C, and the discomfort rate dropped to 33%. The study also compares annual cooling loads according to two different temperature setpoint ranges. The results show that using the fixed setpoint defined by the ISO-7730 standard leads to an increase of 38% in air conditioning load compared to the adaptive setpoint ISO-15251.

Keywords

Trnsys, Thermal Comfort, Cooling, Cool Roof, Tropical Climate

1. Introduction

Buildings significantly contribute to global energy demand, accounting for 30 to 40% of the total worldwide energy consumption. In the building sector, electricity usage is notably high, constituting approximately 42% [1]. This substantial energy

consumption trend is expected to persist, especially in Africa, due to rapid population growth and an annual urbanization rate of 3.5%, the highest globally in recent decades. Consequently, energy demand in Africa is projected to rise by 50% between 2006 and 2030 [2].

Conakry, the capital of Guinea, emerges as the most densely populated city in the country according to RGPH-3 [3]. It hosts a diverse population from various backgrounds. However, this demographic expansion is accompanied by a housing shortage. Presently, Guinea lacks thermal regulations, fostering the proliferation of self-constructed buildings. Unchecked construction often compromises resident comfort and fails to meet established standards.

To address increasing energy demands, especially in tropical regions, cool roofs have gained traction as an effective solution. These roofs, designed with high solar reflectivity, aim to enhance indoor thermal comfort while reducing reliance on air conditioning systems [4]. While cool roofs offer significant benefits, their effectiveness hinges on various factors, including local climate conditions, building characteristics, and indoor temperature regulation practices [5]. Recent research in tropical climates demonstrates promising results: cool roofs can decrease indoor temperatures by 1 - 5°C [6] and potentially cut air conditioning loads by 10 - 30% [7].

However, it's crucial to note that actual energy savings from cool roofs depend on how building occupants manage indoor temperature settings [8]. Rawat and Singh (2021) reported that applying a cool roof to a building in a tropical climate can lead to an average energy saving of 35.7%, along with a reduction in roof temperature of about 2.4°C [9].

Although many studies have been conducted on the effectiveness of cool roofs in tropical climates, our literature review has revealed a lack, or even absence, of research on the impact of cool roofs in the city of Conakry, Guinea.

This paper focuses on examining the impact of cool roofs on thermal comfort and energy consumption in Conakry, Guinea, known for its hot and humid tropical climate through a dynamic thermal simulation using Trnsys-Contam coupling. In addition, we explore the influence of indoor temperature setpoints on the energy savings achievable with cool roofs. Our aim is to quantify these relationships for typical building types in Conakry, in order to assess the potential of cool roofs in improving thermal comfort and reducing energy consumption in this tropical region.

2. Methodology

2.1. Study Area: Conakry

The Republic of Guinea is located in the southwest of West Africa and covers an area of 245,857 km². It is a coastal country with 300 km of Atlantic coast, halfway between the equator and the Tropic of Cancer between 7°05 and 12°51 north latitude and 7°30 and 15°10 west longitude. It is bounded to the west by the Atlantic Ocean, to the south by Sierra Leone and Liberia; to the east by Ivory coast and

Mali; and to the north by Guinea Bissau, Senegal and Mali. [10].

It is subdivided into four natural regions, namely Maritime Guinea, Middle Guinea, Upper Guinea and Forest Guinea (Figure 1). The Koppen classification [11] defines Guinean climate as Aw and Am, respectively “tropical savannah” and “tropical monsoon”. It is subject to the alternation of two seasons (dry, rainy). The dry season generally lasts 7 to 8 months with fairly high temperatures.



Figure 1. Guinea in Africa.

2.2. Climate Data

The climate data used in this study are derived from a combination of measured and selected historical data from Meteonorm in the TMY2 format [12].

Maximum temperatures in Conakry reach around 40°C. The warmest month of the year is April, with an average temperature of 28°C, while the coldest month is August, with an average temperature of 25°C. The high relative humidity indicates that the coastal influence predominates and dominates the climate zonation. It averages more than 70% all year and may sometimes reach 85% or even 90% during the rainy season, especially in August and September. During the year, solar radiation on the horizontal surface reaches a maximum of 1000 W/m² and an average of 230 W/m² (Figure 2).

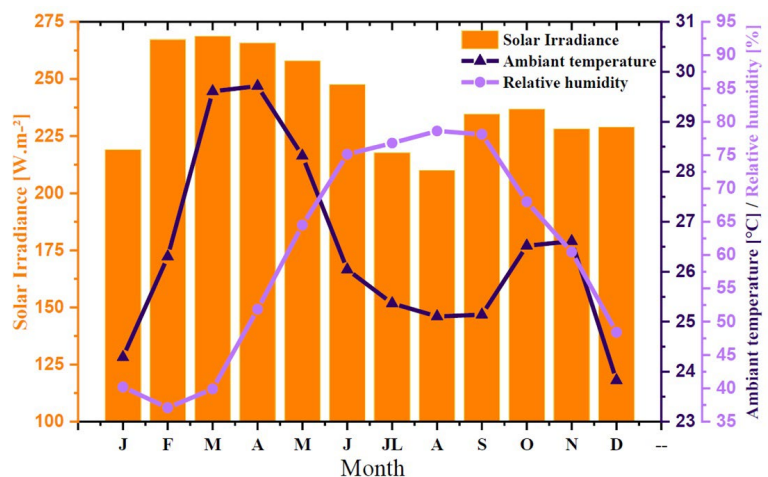


Figure 2. Meteorological data.

2.3. Building Description

A residential building in Conakry, the case study is an existing structure with 112 m² of square space, a ceiling height of 3 m, 8 thermal zones, 3 bedrooms (BR1, BR2, BR3), 2 bathrooms (WC1, WC2), 1 dining/living room (LR), and a hallway/entrance (DGMT) (**Figure 3**).

With a thickness of 6 mm and a g-value of 0.82 and a U-value of 5.74 [W/m²·K], the windows are single-glazed.



Figure 3. Residential building.

The thermophysical properties of the building materials, *i.e.* thermal conductivity λ , density ρ , and specific heat C_p , are listed in **Table 1**.

Table 1. Thermophysical properties of materials.

Materials	e [cm]	λ [W/m·K]	ρ [kg/m ³]	C_p [J/kg·K]
Cement plaster	2	1.15	1700	1000
Cinder block	20	1.05	1300	640
OSB	1	0.13	650	1700
Galvanized steel sheet	0.5	50	7800	450

The building's occupancy is taken into account, bearing in mind the residents' habits and the various scenarios are listed in **Table 2**.

Table 2. Occupancy scenarios.

Zones/Schedule	9 PM - 6 AM	6 AM - 12 PM	12 PM - 4 PM	4 PM - 9 PM
BR1 - BR2	1	0	1	0
BR3	1			0
LR	0	1	0	1

0 = unoccupied; 1 = occupied.

2.4. Modeling

The building is modelled in SketchUp using the TRNSYS3D plugin, then imported into TRNSYS18 [13] to assess thermal performance and dynamically coupled to Contam© [14] for the aeraulic portion. Every time, the Type 56 (Building Thermal Model) of Trnsys determines the inside air temperature of each zone

based on the building's thermal characteristics, charges, and air leakage and ventilation debits. Meanwhile, the Type 97 (Combining with Contam) determines the air leakage between the interior and exterior zones based on external requests and the knowledge of the interior temperatures. The effect of airflow and thermal exhaustion causes infiltration and natural ventilation deficits.

The wind pressure coefficients on the envelope are determined for each wall based on the speed and angle of incidence of the wind on it, as proposed by swami & Chandra [15]. The solar protection provided by the advancement of the roof above the terrace is accounted for by the modeling of two solar masks (one for the living room (LR) zone and the other for the entrance DGMT zone) (Figure 3). To begin the calculation, an additional year of regime change is used. The simulations are run in an hour time. Aerodynamic exchanges (infiltrations, window openings, and interzonal exchanges) are based on the mass conservation law, and the opening models are represented as follows:

$$Q = C \cdot \Delta P^n \quad (1)$$

where Q is the volumetric air debit, C is the air debit coefficient, P is the pressure difference between the two sides of the wall, and n is an exponent characteristic of the flow set to 0.67. The infiltration depth has been set at $2 \text{ m}^3 \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ under 4 Pa, which corresponds to non-joined windows according to the 3CL-DPE method [16]. Each debit coefficient is calculated in relation to the corresponding surface.

3. Results and Discussion

3.1. Reference Case

In the first instance, simulations were run to determine the various temperatures of thermal zones. This reference case assumes that all of the openings are closed. The ventilation is reduced to a basic infiltration calculated using non-joined windows. The solar absorption coefficient of the roof is 0.6 and the infiltration calculate by Contam is 0.2 vol/h. These cases study will be used as a reference in the future to evaluate the performance of cool coating strategy.

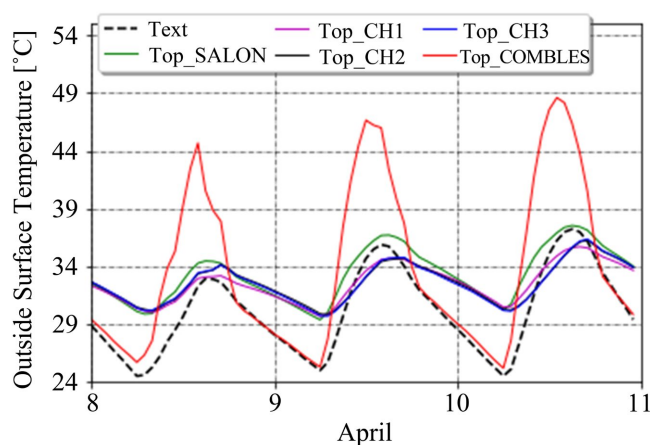


Figure 4. Operative temperature on thermal zone.

The simulation was carried out over three days during the hottest week of the year, from April 8 to April 11. Initial results show that temperatures in the attic regularly exceed 45°C during peak periods and the other thermal zones have average temperatures of 30°C (Figure 4).

The temperature of comfort T_{conf} which determines the number of degrees-hours of discomfort per year in various thermal zones, was calculated using the De Dear expression [11], which corresponds to the upper limit of the category II of adaptable comfort, and the relation (2).

$$T_{conf} = 0.33T_{air,ext} + 18.8 \pm 3 \quad (2)$$

where:

$$T_{air,ext} = \text{radiant mean temperature.}$$

The recorded degrees-hour represent the difference between the temperature at each hour of the working day and the comfortable temperature. The rate of distress is defined as the ratio of the number of hours of distress to the number of hours of work. The corresponding results are shown in Table 3.

Table 3. Discomfort rate on thermal zone in reference building.

Zone	Hours of occupancy (a)	Hours of discomfort (b)	Discomfort rate [%] (b/a)
BR1	4745	2200	46
BR2	4745	2286	48
BR3	6935	2551	36
LR	4015	2297	57

Figure 5 shows the number of degrees obtained for the Salon during the year. The hours of the day are represented in order, while the months of the year are represented in abscises. It is possible to detect that discomfort is present almost all year and is more noticeable during the months of March and April, especially at night.

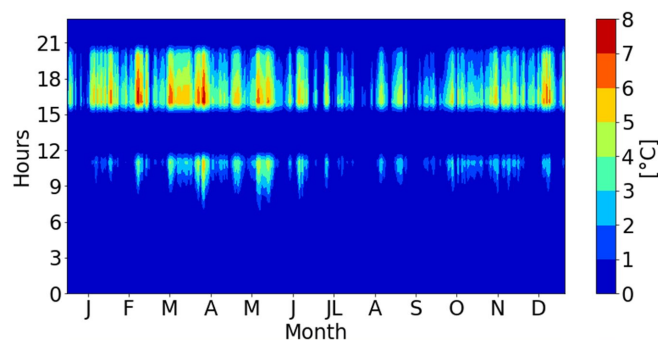


Figure 5. Evolution of discomfort over one year in LR.

3.2. Cool Roof Technique

For cooling the building, the cool roof technique was evaluated with an absorption

coefficient of 0.3, which corresponds to a reflection of 0.7; the roof surface temperature dropped from 54°C to 39°C, a reduction of 15°C, which corresponds to 31% (Figure 6).

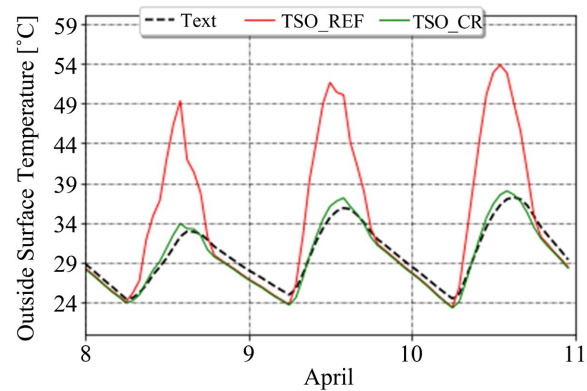


Figure 6. Impact of cool roof on surface temperature roof.

The operating temperature of the living room thermal zone also dropped by 2.4°C and the discomfort rate calculated in Table 2 for the various thermal zones fell from 57% to 33%, *i.e.* a 42% reduction in the discomfort rate (Figure 7).

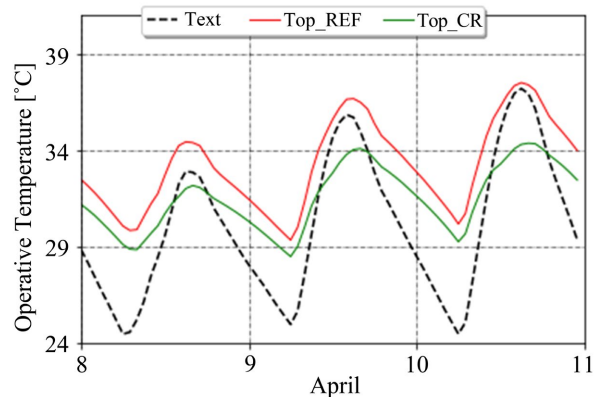


Figure 7. Impact of cool roof in LR.

The impact of the cool roof on all the building's thermal zones is shown in Table 4, and the reduction of discomfort over the year in the LR is also shown in Figure 8.

Table 4. Discomfort rate on thermal zone in building with cool roof.

Zone	Hours of occupancy (a)	Hours of discomfort (b)	Discomfort rate [%] (b/a)
BR1	4745	593	12
BR2	4745	784	16
BR3	6935	875	12
LR	4015	1362	33

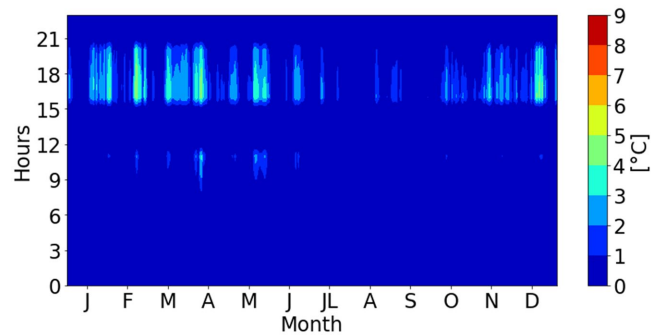


Figure 8. Reduction of discomfort over one year in LR.

3.3. Energy Consumption

To assess the impact of the comfort zone on the building's energy consumption, two different standards were used. The first is ISO-7730, which recommends heating at 20°C and cooling at 26°C; the second is ISO-15251, whose heating and cooling conditions are governed by equation (2).

Figure 9 shows the building's annual cooling loads in the living room area for the two set-point temperatures compared. The comparison shows that the temperature required by ISO 7730 causes a higher air-conditioning load than the adaptive one (ISO-15251); an increase of 38% is observed in the reference case and 67% after the incorporation the cool roof.

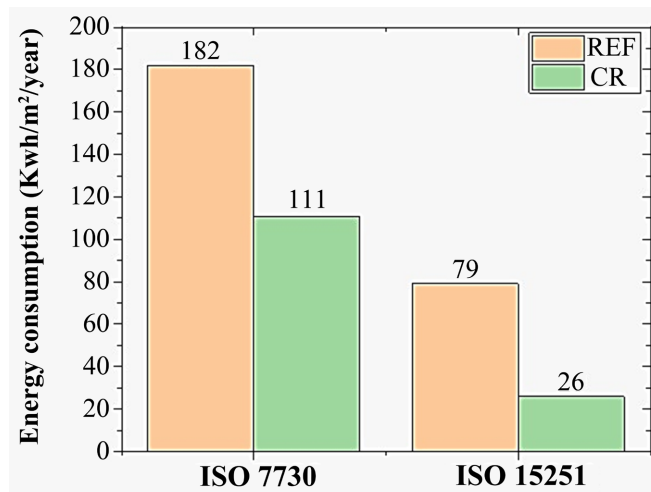


Figure 9. Reduction of discomfort over one year in LR.

4. Conclusions

This study demonstrates that cool roofs can generate substantial thermal and energy benefits for buildings in Conakry, Guinea's hot and humid tropical climate. Applying a roof with a solar absorption coefficient of 0.3 significantly reduced indoor temperatures and discomfort rates. Even greater energy consumption reductions could be achieved by using adaptive rather than fixed temperature set-points. The results support adopting policies and practices promoting cool roof

use in new constructions and renovations in Conakry to curb the rising cooling demand in this tropical region.

The authors call for the involvement of policy makers and stakeholders in the construction sector in Guinea to develop national standards governing the use of alternative materials and industrial by-products in construction material formulations. Furthermore, they encourage the implementation of regulations promoting the controlled incorporation of local or recycled materials, while enforcing strict criteria related to mechanical performance, durability, and environmental safety.

Acknowledgements

Mamadou Aliou II DIALLO and co-authors. would like to thank the Islamic Development Bank for funding this scholarship, as well as the Guinean government.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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