Contents lists available at

Journal of Environmental Management and Safety

Journal homepage: www.cepajournal.com

ROOF FAILURES IN THE HOT-HUMID TROPICAL ENVIRONMENT: EVIDENCE FROM ENUGU URBAN, NIGERIA.

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ARTICLE INFO

Article history
Received 28th May, 2022.
Received in revised on 3rd June, 2022.
Accepted on 8th June, 2022.
Available online 13th June, 2022.

Keywords:
Building/house types; Design and construction; Roof failure; Roof design; Hot-humid; Enugu urban, Nigeria.

ABSTRACT

In recent times, the issues of roof failures in urban Nigeria have become a source of concern to house owners and building industry professionals. Although several key cases of roof failures have been investigated in South-west Nigeria, this building problem is yet to be adequately explored in the Southeast sub-region of the country. Hence, fuller understanding of the nature, rate and causes of roof failures in the former sub-region, where our study area is major urban centre is lacking. The study is aimed at identifying the major causes of roof failure in Enugu urban, Nigeria with the intent of evaluating the common types of the occurrence, so as to proffer a lasting solution to building design professionals, stakeholders and house owners on measures through which roof failure can be minimized. The study adopted descriptive cross-sectional survey involving observations and interviews. Employing purposive sampling technique, nine neighbourhoods in Enugu urban was selected for the study, based on the frequency of roof renovation going on in those areas as personally observed by the researchers. Primary data was collected through participant observation, photographic documentation and oral interviews based on randomly selected buildings and houses and residents within the neighbourhoods under study. The data collected was analyzed using descriptive statistics such as bar charts and frequency distribution tables. The results show that the major causes of roof damages are deficient roof design,

poor maintenance culture, bad workmanship and use of sub-standard materials. The article concludes that roof design and construction require special knowledge and skill with regular routine maintenance to address the situation. It recommends that climatic consideration of its design and construction be given utmost attention especially in the hot-humid tropical climate.

1.0 INTRODUCTION

Roofs are an integral part of building and account for significant costs of building structures. They are the exterior surface on top of buildings or frame-works of supporting structures comprising of either timber, concrete or steel members, on which covering materials such as corrugated sheets (aluminum, zinc, asbestos etc.) or even tiles and shingles are placed. As the most exposed parts of buildings to the elements of weather, roofs serve as a protective barrier as well as structural support alongside walls and columns (Morrison, 2010). By implication, just as well designed and constructed roof structures can compensate for several problems that might occur in other parts of affected building, the consequences of roof failures can be equally enormous and devastating (Amini & van de Lindt, 2013)

The determinant factors of roof performance are lifespan of the entire structure and characteristics of the components such as appearance, material strength and resistance, as well as chemical and physical qualities. This performance index is significant because roofs are considered the most battered parts of houses and buildings owing to their unceasing exposure to agents of degradation in typical hot-humid tropical weather like Nigeria, arising from sun rays, wind, torrential rainfalls, etc (Amini & van de Lindt, 2013, Guha & Kopp, 2014). Aside the recurrent wetting and drying, heat and cooling, leaching and rust, the roof structure ought to put up with additional loads from external sources in order to be seen to be performing effectively. Among all the anomalies or deficiencies which roofs are subjected to, not all become pathological while some be catastrophic (Piskoty et al., 2013). The level of their impact may not imply a critical situation, meanwhile many anomalies may lead to the same type of damages (Manuel et al., 2017)

In Nigeria, roof failures have risen alarmingly in recent years. The failure is endemic because of its disproportionate occurrence and intractable nature within the past few decades. These failures manifest in diverse ways such as blow off, sheet removal, truss damage, sagging etc (Adesogan, 2018) but are widely noticed in the high rate of re-roofing projects (in part or in full) in most districts of the city. Anecdotal evidences reveal that rate of roof blow off in both residential and public buildings during the rainy season is high and the public and institutional buildings are mostly affected. This has both huge psychological effects and financial implications on building occupants and owners alike (Okeke et al., 2022). Roof failures not only endanger occupants of the houses, they also lead to water intrusion, resulting in subsequent damage to household items inside, such as furniture and appliances (Alhawamdeh & Shao, 2021). In view of the forgoing and coupled with the high cost of building materials in Nigeria, there is need to investigate the causes of roof failure in Nigerian cities. This study aims to identify the major causes of roof failure in Enugu urban, Nigeria with the intent of evaluating the common types of the occurrence, so as to proffer a lasting solution to building design professionals, stakeholders and house owners on measures through which roof failure can

be minimized. The specific objectives of the study were to;

Examine the rate and types of roof failure commonly experienced in Enugu urban.

Identify the major causes of roof failure in the study area, and

Suggest measures for curbing roof failure in the study area and further afield in Nigeria.

A useful contribution of this research is to the ongoing discussion concerning climate change and the environmental effects of the built environment in southeast Nigeria. The study highlighted the most common reason and peculiar types of roof failure in Enugu city. Therefore, the findings of this study are expected to inform architects, urban planners, and managers on how to address the rising rates of roof failure in urban residential neighbourhoods through effective designs, appropriate use of materials and the adoption of appropriate construction techniques in order to mitigate the effects on urban residents in Nigeria.

2.0 LITERATURE REVIEW.

According to Collins dictionary, failure is understood as an act or instance of falling or proven unsuccessful. It connotes lack of success and deterioration especially in strength and quality. Studies have shown that most roof failures occur at bolted connections that were either inadequately secured at the time of construction or that have since failed due to deterioration (Adesogan, 2011). Many roof designers often overlook design factors such as tolerance, durability, maintenance rate, load, energy efficiency and factors of safety, and these could result in roof failure.

2.1 Types of Roof Failures

Failure in roofs can be defined as any form of behaviour in the roof that seems to threaten the safety of the roof in terms of serviceability or which could lead to total collapse (Adesogan, 2011). There are three broad categories or classes of such failures based on the extent of damage to the roof members and materials. These are; ultimate limit state generally connected with total collapse, serviceability limit state associated with deflection and vibration and special requirements failure connected with functionality, for instance, aesthetics, fatigue, fire resistance, and water tightness (Chukwuneke,2000).

- **Ultimate failures**: These may involve the structural collapse of the roof. It may occur as a slow structural collapse known as plastic failure or sudden failure. This type of failure is usually disastrous in nature and more widely publicized than the serviceable failures. An example of ultimate limit state failure is roof blown-off (Blake, 2001).
- **Serviceability failure**: This type is fairly frequent form of structural failure observed in roofs' frame and covering material. It occurs in the form of deflection and cracks on a structural member, or a breakdown of water proofing cover which could result into water penetrating the roof, in case of concrete, initiating corrosion of reinforcements and in wood structure, causing decay and eventual deterioration. They could lead to disruption of services and interruption of business activities (Blake,2001).
- **Special requirement failure**: This is a functional purpose requirement that has to do with special requirements other than the normal roof functions. For example, in design of music studios, special precautions are built into the roof frame to reduce the noise penetration and the acoustics. The requirement in radiation protection buildings is to prevent leakage of radioactive elements; and so, here the

special requirement is to prevent porosity (Ayoade,1995).

2.2 Roof Failure and Hot-Humid Tropical Environment

-Variations in moisture content.

The life expectancy of roofs is greatly influenced by the presence or absence of roof maintenance programme just like every other building component. According to the National Roofing Contractors Association in Canada, roofs that are not properly maintained will last approximately half of their anticipated normal service life (see Adesogan, 2011).

Adesogan (2011) further opined that roof characteristics are dependent on at least four factors (i) purpose of the building that it covers, (i) available roofing materials-, the accessible construction technology (iii) wider concepts of architectural design and practice-: and governance regime as defined by local or national building codes. Although modern architecture has given rise to different types of roof designs and construction, all roofs, can however be broadly classified into two types on the basis

2.3 Causes of Roof Failure

Causes of roof failure can be classified based on design, construction, maintenance, environment and age of the building in question. Some authors have noted that aspects such as the design of slopes, thermal insulation and the ventilation systems or the specification of incompatible materials are the most frequent design errors (Garcez et al., 2015). Most roof designs are based on rule-of-thumb, past experiences, intuitions and common senses of the carpenters and building owners. Even professionals are also sometimes trapped in the same subjective reasoning and practices.

One common design oversight and error in the construction of roof eaves and ridges has to do with diminutive roof eave span that causes undue exposure of external walls and other building components to incessant rain and sunlight. Consequently, the affected walls: - cement plasters, painted surfaces and other exposed materials gradually become leached, dis-coloured, and defaced besides other damages. Other design/construction deficiencies that might predispose a roof to fail due to associated weak joint also include insufficient roof slope and use of multiple ridges. Errors in construction of roof systems either as a result of lack of proper supervision by professionals or the use of under trained roofers (carpenters, installers etc.) have also a major cause of roof failure. Prevailing wind, site topography and prevailing microclimate were also some of the factors identified to have influence roof failures. Majority of the buildings with nail removal and open laps are as a result of exposure to high prevailing wind. Some materials used as roof covering in Enugu urban are inadequate either as a result of poor quality or lack of compatibility with hot-humid tropical environment.

2.4 Research Methodology

The study was carried out within the three local government areas that make up Enugu city namely; Enugu North, Enugu South and Enugu East. Nine urban neighbourhoods were selected from these local government areas based on purposive sampling technique. They include Coal camp/Ogbete, Asata, Uwani, Ogui New-Layout, New Haven, Independence Layout, Government Reserve Area (GRA), Trans-Ekulu, and Achara Layout. Though the city of Enugu comprises the population of the study, the sample size was selected from nine neighbourhoods as mentioned above which is more than 60% of the study area.

This study adopted a mixed research method and employed a descriptive cross-sectional survey involving observations, questionnaire survey and personal interviews. The choice of this research design was informed by the

nature of the research objectives and the evidence in the literature showing that most of the previous studies on this subject were based on cross-sectional surveys (see Adesogan, 2011; Manuel et al. 2017).

Observation schedule and photographic materials were used to record observations made during the fieldwork. Photographs of different types of roof failure and possible causes of roof damages were taken on the spot. The types of roof damages identified from the literature review were used to benchmark the existing damages identified in the study area. The failures were categorized into six groups, namely: Material related failure, Environmental related failure, Maintenance related failure, Construction related failure, Design related failure and Age-related failure.

The self-administered questionnaires were derived from the findings of the review of literature and were arranged into three sections. One copy of the questionnaire was administered by hand to randomly selected household heads or adult representatives met in each of the houses visited during the survey. The first section focused on the participants' personal socio-economic and demographic characteristics such as gender, age, marital status, highest level of education, profession, employment status and others. The second section required the participants to rate the incidence of roof damages in their neighborhoods, types of roof damages and possible causes. The third section sought to retrieve historic accounts of roof failure and maintenance, roof types, materials used in the construction of roof trusses, sheathing and others.

House owners, artisans, professionals and developers were also interviewed. Data from interviews were recorded with tapes and augmented with field notes to capture nonverbal communication. Analysis was done concurrently with questionnaire data (Creswell, 2009) and the tape record was transcribed into texts (Bell, 2009).

The survey took place in the study area between February and October 2020. The timing rationale is to cover part of dry season when most people normally embark on roof renovation and rainy season when roof failure is most noticeable. Prior to the main survey, a pilot survey was conducted to pre-test the questionnaire using selected building industry professionals and the feedback was incorporated into the final version of the questionnaire. Participants in the survey were randomly selected from the neighbourhoods mapped out for the study but preferences were given to professionals who are knowledgeable in the building industry. A total of 250 copies of questionnaire were administered by the researchers to the residents, but 185 copies were retrieved and found to have been correctly filled representing around 74% response rate.

The descriptive statistics were used in the data analysis to compute the frequencies and percentages of the variables (i.e., the causes, rate and types of roof failure, etc.).

2.5 Results

Table 1 shows the socio-economic and demographic characteristics of the participants.

TABLE 1: SOCIO-DEMOGRAPHIC CHARACTERISTICS OF THE RESPONDENTS IN THE SURVEYS ON ROOF FAILURES IN ENUGU URBAN, NIGERIA (n=185)

S/n	Variable	Categories	Frequency	Percentage (%)
1	SEX	Male	150	81.08
		Female	35	18.92
2	AGE	31-40yrs	73	39.46
		41-50yrs	62	28.11
		51-60yrs	31	22.16
		60andabove	19	10.27
3	HIGHEST LEVEL OF EDUCATION ATTAINED	No Education	20	10.81
		Primary School	25	13.51
		Secondary School	31	16.75
		Post-Secondary School	100	54.05
		Higher Degree/s	9	4.86
4	OCCUPATION/PROFESSION	Architect	48	25.95
		Civil Engineer	40	21.62
		Building Contractor	22	11.89
		Trader	44	23.78
		Others	31	16.76
5	STATUS OF OCCUPANCY	Rent Paying	135	72.97
		Non-Rent Paying	20	10.81
		Official	-	-
		Mortgaged	-	-
		Owner Occupier	30	16.22
6	LENGTH OF STAY WITHIN THE NEIGHBOURHOOD	Less than 1 year	32	17.30
		1 to 5 years	65	35.14
		6 to 10 years	40	21.62
		11 to 20 years	20	10.81
		More than 20 years	28	15.14

Source: Researcher's fieldwork (May, 2020)

The results indicate that all the respondents irrespective of their gender have minimum of secondary school education. Most of them were working class citizens engaged with either the public or the private sector while some are self-employed. The respondents were mostly male, family head sand belong to age groups ranging from 31-50 years, 51-60 years and 60 years and above. A majority of the respondents were renters. However, there were also some owner occupiers. It can be inferred that the respondents are qualified to provide reliable data on the subject matter. Table 2 presents

data focused on respondents' perception on forms and causes of roof failure in Enugu metropolis.

TABLE 2: RATE, TYPES AND CAUSES OF ROOF FAILURE IN THE NEIGHBOURHOODS SURVEYED

S/n	Variables	Options	Frequency	Percentage (%)
1	Rate of roof failure	Very Low	10	5.40
		Low	23	12.43
		Moderate	30	16.22
		High	115	62.16
		Very High	7	3.78
2	Types of roof failure	Roof Blow-Off (RB)	20	10.81
		Pulling of roof covering/flashing (PCF)	65	35.14
		Nail withdrawal (NW)	20	10.81
		Discolouration (D)	20	10.81
		Rusting (R)	5	2.7
		Sagging of trusses (ST)	8	4.32
		Leakage (L)	37	20
		Wood Decay (WD)	10	5.41
3	Causes of roof failure	Material Related Failure (MRF)	25	13.51
		Environmental Related Failure (ERF)	17	9.20
		Maintenance Related Failure (MRF2)	23	12.43
		Construction Related Failure (CRF)	48	25.95
		Design Related Failure (DRF)	30	16.22
		Age Related Failure (ARF)	42	22.70

Source: Field survey (2021).

Table 2 shows the results of the rate, types and causes of roof failure in the neighbourhoods investigated. Data from the questionnaire survey as in Table 2 indicate that the rate of roof failure is high in Enugu urban. Also, from field observation and interviews with professionals the rate of roof failure was found to be high. Roof failure as shown in figure 1 manifests in many ways within the neighbourhoods which include as roof blow-off, pulling of roof covering/flashing, nail withdrawal, discolouration, rusting, sagging of trusses, leakage and wood decay. However, pulling of roof covering/flashing (PCF) has the highest occurrence rate and Rusting exhibited the least.

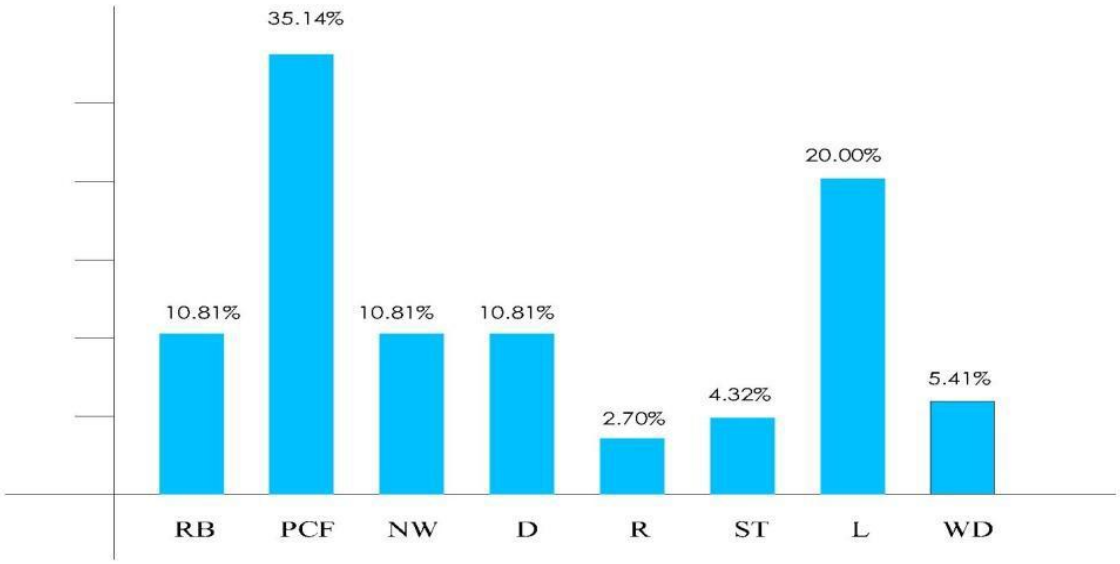

Figure 1: Percentage of roof failure by type of damage.

Majority of the buildings with nail removal and open laps were as a result of exposure to high prevailing wind as evident in figure 2. Most cases of roof failure were construction related failure (CRF) or age-related failure (ARF)

Figure 2: Classification of roof failure according to causes

	Damage Type	**Photograph**	**Comment**
1	Pulling of roof Fascia.		Pulling of roof fascia/flashing in Residential building in Trans-Ekulu area. Roof fascia is mostly attacked by wind and should be firmly fixed. In the case of eave flashing, their fastening should be carried out with care.
2	Total collapse of roof structure/trusses.		Total collapse of roof structural of mechanic workshop in University of Nigeria Enugu campus. Total collapse of roof structure/trusses is often as a result of poor bracing and wood type and strength.
3	Poorly maintained concrete roof gutter and spouts.		Poorly maintained concrete roof gutter and spouts of a lecture hall in University Nigeria Enugu Campus.
4	Reroofing as a result of low pitch.		Total reroofing of 3-bedroom block of flat in achara layout due to low pitch height and subsequent failure

5	Defaced external walls		Defaced walls as a result of inadequate roof eave at Enugu State Ministry of Gender affairs and Social Development Building (Independence layout)
6	Failed barrel vault concrete roof.		A failed concrete roof now covered with stepped long span aluminum sheet as well as defaced walls due to water seepage from failed concrete at Trade fair complex (Golf Estate)
7	Discolouration of roofing sheet.		Discolouration of sand coated acrylic roofing tiles in New haven
8	Failed flat roof.		Failed flat roof being re-roofed in an institutional building (GRA).

Table 3: photographs showing the various types of damage indicated in table 2
Source: Researcher's field work (2020)

2.6 Discussion

Based on the objectives of this study as outlined in the introductory section, three key findings have been identified. First, out of the eight different types of roof failure, sheet removal is the most prevalent in Enugu neighborhood. This problem is traceable to poor workmanship and handling of roofing materials. It further deteriorates and leads to more roof failures such as nail removal and leakages within the interior

spaces of the building thereby shortening the life expectancy of the roof (Nurul and Md Azree 2014). Hilary et al (2018) asserts that people patronize unskilled craftsman because they want to optimize their resources and the workers work with little or no supervision.

Complete roof blow off is also a common occurrence in the study area and such incidents happen mostly during heavy rain storms. Inadequately braced roofs resulting from poor workmanship were most susceptible to this kind of failure. This attitude has left so many roofs to be structurally insufficient to withstand the environmental forces of attack.

Secondly, we now know that most roof designs are based on rule-of-thumb, past experience, intuition and common sense of the carpenters. Errors in construction of roof systems either as a result of lack of proper supervision by professionals or use of undertrained roofers (carpenters, installers etc) was observed as one of the major causes of roof failures in the study area. This finding is also consistent with Adesogan (2018), on a Study of Roof Failures. Proper site analysis to determine wind loads, environmental and climatic influences on the roof are seldom carried out in Enugu neighbourhood. Majed and Zhonghua, (2018) highlighted that Climate conditions play an essential role in selecting the roofing method and any selected method should respect a building's needs to adapt to weather conditions. Furthermore, some roofing materials such as galvanized Zinc and concrete decks used as roof covering in Enugu urban are inadequate either as a result of poor quality or lack of compatibility with hot-humid tropical environment. This finding is in line with Nurul and Md Azree (2014) and the submission of Nwalusi and Okeke (2021), who asserted that the application of local building materials and appropriate technology perceived as more satisfying, convenient and prestigious is on the decline in developing cities. Such materials obviously cannot withstand the ultraviolet rays of the sun in the tropics.

Anecdotal evidence gathered from other professionals in the building industry reveals that Nominated roof suppliers are accustomed to speak of roofs in terms of "life span at approximately a period of twenty years". They are also aware of numerous examples of roofs that have ceased to perform or to remain water tight, well before time. This is often referred to as premature failure. Under closer scrutiny, evidence revealed that these "failures are rooted in an inappropriate initial design, improper installation of materials, misunderstanding of the roof's particular requirements or a disregard for the need to provide routine and regular maintenance"

Ongoing empirical evidence also shows that "the two most frequent causes of roof failure in the study area are related to construction and age of roof". These materials especially corrugated galvanized zinc roofing sheet is prone to rusting and discoloration over time and is supported by Adesogan (2018). Therefore, discolorations of roof coverings were common sight as obviously they cannot withstand the ultraviolet rays of the sun in the tropics. The built-up concrete roofing decking is popular among institutional buildings in Enugu Urban. This implies that most of the institutional buildings have flat roofs or low-pitched roofs. When the failure rates are compared to the life expectancy of 15-20 years of built-up roof (BUR), it suggests that this system is not conducive for use under tropical conditions. In the tropical environment, the temperature remains high through the year with a daily mean temperature of about 80–90-degree F (Aniekwu,2014). This temperature condition exposes the bituminous felt (a

waterproof membrane) to damage. Failure ultimately results from the inability of the felt (which is generally of mats of organic or inorganic fibers coated and impregnated over a solid concrete deck) to withstand more than slight amounts of stretching without tearing or splitting. Aniekwu, (2014) also asserts that the standard tests to which these materials are subjected to before certification are designed for climatic conditions considerably different from those of the tropics. The B.S. 747, for instance, specifies requirements for countries having a climate similar to that of the British Isles. This climate condition is not a tropical type and consequently cannot be adequate for certification of materials for use under tropical exposure. It was observed therefore that a number of flat roofs had been re-designed to pitch roofs, to suite the tropical conditions of the study area.

3.0 C ONCLUSIONS AND RECOMMENDATIONS

The article explored the nature, characteristics and the inter-relationship between the various causal factors of roof failures in the city of Enugu, Nigeria. The following conclusions and requisite recommendations were offered;

- The factors responsible for these failures are those of construction, age, design, choice of material, maintenance and the environmental influences on roof. The working drawing and technical documents used during roof construction process should be carefully detailed. The design technicalities and recommendations should be detailed and comprehensive in order to serve as a basis for consultations between roofers and designers.
- The type of failures to which roofs are often subjected include sheet removal, open lap, nail withdrawal, rusting, discolouration and total blown-off in extreme cases.

Consequently, the recommendations are as follows;

a. Good quality workmanship plays an important role in the performance of a roof and hence should be encouraged. It is important that appropriate experts are consulted in the choice of material and erection of roofs at the outset.
b. The use of low-quality roofing materials in the study area should be discouraged.
c. Maintenance culture should be improved. People should examine their roofs regularly at least once a year after every raining season. This will enable them to detect clogged/blocked roof gutters and spouts, weak or damaged roof members, as well as leakages which might lead to further deterioration on time thereby reducing costs of repair. Heavily shaded trees around roofs should be trimmed from time to time as to reduce the amount of debris on roofs.
d. Corrosion comes with age and reduces the thermal insulation of the roof material. A corroded roof should be scrapped and repainted with red oxide and aluminum paints to improve reflection.
e. More attention should be paid to roof design particularly the slope and roof overhang. The use of decked flat roof should be discouraged as it is obviously not suitable for hot-humid tropical climate.

FUNDING

The authors received no financial support for the research, authorship, and/or publication of this article

COMPETING INTEREST

The authors declare no conflict of interest

ACKNOWLEDGMENT

The authors wish to acknowledge the support of Prof. Ibem O. Eziyi and Arc Francis O. Okeke, both of the Department of Architecture University of Nigeria, for their technical contributions to this research.

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