

Typology, Prevalence, and Failure Mechanisms of Dampness in Public Secondary School Buildings in a Tropical Climate: A Diagnostic Building Pathology Study from Adamawa State, Nigeria

Joseph Philip Gassa

gassajp@yahoo.com

Kabiru Maiunguwa

Research Article

Keywords: dampness typology, capillary rise, wind-driven rain, interstitial condensation, material degradation, tropical buildings, building pathology

Posted Date: August 3rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10359064/v1>

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Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Journal of Building Pathology and Rehabilitation on October 7th, 2026. See the published version at <https://doi.org/10.1007/s41024-026-00917-4>.

Abstract

Dampness remains one of the most frequently reported causes of building deterioration in tropical climates, yet its typology, underlying transport mechanisms, and material-degradation consequences in public educational infrastructure remain under-documented in the literature on Sub-Saharan Africa. This study diagnoses the common types, spatial distribution, and physical causation of dampness in a complete census of ten Grade-A public secondary schools (the full statewide population of this school category) across the five educational zones of Adamawa State, Nigeria. Using a cross-sectional observational design, a face- and content-validated diagnostic checklist was administered by the researcher across urban and semi-urban school sites within this fixed population, classifying each recorded case by established visual indicators of capillary rise, wind-driven rain penetration, or surface/interstitial condensation. Checklist data (278 recorded cases) were analysed using descriptive percentages with 95% Wilson confidence intervals, and association between categorical variables was tested using Pearson's chi-square with Cramer's V as an effect-size measure. Findings show that penetrating dampness is the most frequently observed type (133 of 278 cases, 47.8%, 95% CI [42.0%, 53.7%]), followed by rising dampness (110 cases, 39.6%, 95% CI [34.0%, 45.4%]), while condensation dampness was the least prevalent (35 cases, 12.6%, 95% CI [9.2%, 17.0%]), a pattern consistent with, though not direct proof of, wind-driven rain ingress at roof-wall junctions, corroded fasteners, and degraded flashing details in the corrugated-sheet roofing that dominates this building stock, rather than with ground-moisture capillary action alone. The confidence intervals for rising and penetrating damp overlap, so the two leading mechanisms are not sharply separated at this sample size, though both are clearly and significantly more prevalent than condensation. The distribution of damp type differs significantly by educational zone (chi-square = 16.82, df = 8, p = 0.032, Cramer's V = 0.17), with Mubi zone recording the highest overall prevalence (23.0%), while the proportional composition of damp types does not differ significantly between urban and semi-urban schools (chi-square = 0.44, df = 2, p = 0.80). The study reframes the contribution of typological survey work in this climatic zone from prevalence documentation toward a mechanism-linked diagnostic baseline capable of directing envelope-specific intervention, and explicitly identifies the absence of instrumental triangulation (moisture metering, relative-humidity logging, thermal imaging) as a limitation for future instrumented validation.

1. Introduction

Dampness is the unwanted presence of moisture within the fabric of a building, arising from rain penetration, capillary rise from the ground, or internal condensation (Godish, 2021; Carmeliet & Derome, 2011). As the most frequently reported cause of building deterioration worldwide, dampness has been documented at scale in the United Kingdom, United States, Australia, Canada and several other high-income countries (World Health Organisation, 2009), where national building-stock surveys and standardised diagnostic protocols have produced comparatively rich typological evidence. The same cannot be said for tropical, resource-constrained public infrastructure: while individual case studies exist for residential and heritage buildings in Ghana, Malaysia, Jordan and Nigeria (Halim & Halim, 2010; Sulaiman & Beithou, 2011; Agyekum & Ayarkwa, 2014; Sani, 2022), systematic, multi-site typological

surveys of public educational buildings in this climatic zone remain scarce, and fewer still connect observed prevalence to the underlying hygrothermal mechanisms and material-degradation pathways that building pathology, as a discipline, is concerned with.

Public secondary school buildings occupy a distinct place in this problem because they combine high daily occupancy, constrained maintenance budgets, and, in much of Nigeria, ageing building stock (Zakariyyah et al., 2020; Toyinbo, 2019). Public secondary schools in Adamawa State, North-Eastern Nigeria, are managed by the state government and its partners, and despite continuous capital investment several buildings remain in a dilapidated state. Building failure in these structures has multiple causes, of which dampness is one; before its impact can be treated or mitigated, however, the specific type, physical causation, and prevalence of dampness affecting a building stock must first be correctly diagnosed, since misdiagnosis is a well-documented cause of recurring damp problems and wasted remediation cost (Riley & Cotgrave, 2005).

This paper is deliberately positioned as a diagnostic building pathology investigation rather than a general condition survey: it asks not only what types of dampness are present and how they are distributed across zones and settlement types, but why, in physical terms, penetrating damp in particular predominates in this building stock, and what that implies for material degradation pathways in masonry, timber and metal components. Unlike prior single-site case studies in the region, the paper also tests the distributional questions formally using chi-square association tests, moving the typology literature in this climatic zone from purely descriptive reporting toward a statistically grounded, pathway-aware diagnostic baseline that can inform where limited maintenance resources are targeted first.

2. Literature Review

2.1 Conceptual Definitions and Classification of Dampness

Three types of dampness recur throughout the building pathology literature: rising damp, penetrating damp, and condensation. A building is generally described as having a dampness problem when its materials become sufficiently damp to cause material damage and visible mould growth (Burkinshaw, 2016; Burkinshaw & Parrett, 2004). Rising damp occurs when ground moisture is drawn upward through masonry by capillary action, typically in the absence of an effective damp-proof course or membrane (Hall & Hoff, 2013; Rirsch, 2013). Penetrating damp results from the lateral entry of rainwater through defective roofing, cracked walls, or poor detailing at openings, and is considered particularly damaging to the structural lifespan of a building (Oliver, 1988; Laeirj, Spence & Laycock, 2013; Ishak & Kayan, 2013). Condensation dampness arises internally when warm, moisture-laden air meets a surface below its dew point, and is closely associated with poor ventilation, occupant density, and thermal bridging (Mumovic, Ridley, Oreszczyn & Davies, 2006; Perry & Green, 2017).

2.2 Moisture Transport Theory: Capillary Rise, Wind-Driven Rain, and Vapour Diffusion

Rising damp is governed by capillary suction in porous masonry: water is drawn upward through interconnected pores whose size, shape and connectivity determine the rate and ultimate height of rise (Gana, 2015; Hall & Hoff, 2013). The absorption process follows a sorptivity relationship, in which cumulative moisture uptake is approximately proportional to the square root of time, a property that can be measured directly from cement-based materials and used to predict capillary behaviour (Yang, 2019). In practice, the potential height of capillary rise is moderated by evaporation at the wall surface before moisture can rise to its theoretical maximum; for this reason, rising damp rarely exceeds about 1.0-1.5 m in unmodified masonry, except where the wall is sealed by vapour-impermeable coverings that suppress evaporation (Gana, 2015). As moisture evaporates, dissolved ground salts (commonly nitrates and chlorides) are left behind at the evaporation front, producing the characteristic tide mark and powdery efflorescence used diagnostically to distinguish rising damp from other mechanisms (Hall et al., 2011). Defective, absent, or bridged damp-proof courses and membranes, bridged by render cracks, earth deposited against a wall, or mortar droppings in a cavity, are the principal proximate causes of rising damp identified in the wider literature (Alfano, 2019).

Penetrating damp is driven by wind-driven rain acting on a building's exposed facade and roof envelope: rainfall intensity, wind speed, and orientation combine to force water through defects such as cracked render, degraded pointing, corroded roof fasteners, and failed flashing at roof-wall junctions (Laeirj, Spence & Laycock, 2013; Ishak & Kayan, 2013). In tropical climates, short-duration convective storms generate rainfall of high kinetic energy and intensity, which increases the wind-driven rain load on facades and roofs relative to the more evenly distributed frontal rainfall typical of temperate climates (Amadi & Higham, 2020). This mechanism is entry-point dependent rather than height-limited in the way rising damp is, which is consistent with penetrating damp staining concentrating near roof-wall junctions, window and door reveals, parapets, and cracks rather than uniformly at low wall level.

Condensation dampness follows a different physical logic entirely: it occurs when the temperature of an internal surface, or of air within a construction assembly, falls below the dew point of the adjacent air, causing water vapour to condense (Perry & Green, 2017; Mumovic et al., 2006). Surface condensation is visually apparent at cold bridges such as uninsulated lintels, corners, and poorly ventilated rooms; interstitial condensation, which occurs within the building fabric itself, can go unnoticed and is potentially more damaging to structural stability because it compromises materials from within without an external visual warning (Evrard & De Herde, 2010). Because this study relied on external and internal visual inspection rather than temperature and relative-humidity logging, it can identify surface condensation reliably but cannot rule out undetected interstitial condensation, a limitation discussed further in Section 3.6.

2.3 Material Degradation Pathways Linked to Dampness

Each damp mechanism is associated with a distinct, physically explicable degradation pathway in building materials. In masonry and mortar, repeated wetting and drying cycles combined with salt crystallisation pressure at the evaporation front cause progressive mortar loss, crumbling plaster, and paint failure, with drying rates governed by the same capillary and diffusion kinetics that govern moisture

uptake (Karagiannis et al., 2017; Franzoni, 2014). Drying a saturated traditional masonry wall can take many months once the moisture source is removed, meaning surface damage often continues to be visible well after the causative defect has been corrected (Karagiannis et al., 2017). In embedded and exposed metal components, sustained moisture presence drives electrochemical corrosion; corrosion products occupy substantially more volume than the parent metal, generating expansive stress that cracks and spalls surrounding masonry or render, compounding the material damage beyond the metal component itself (Hall et al., 2011). In timber, sustained elevated moisture content creates conditions for fungal decay and, in this climatic zone, facilitates termite infestation of softened structural and furniture timber, consistent with the co-occurrence of timber decay and termite indicators reported in the companion structural-stability analysis of this research programme. Chemical treatment approaches to rising damp, including proprietary rising-damp devices and injected damp-proof courses, target this pathway directly by interrupting capillary continuity, though such treatments require the wall to complete its drying cycle before finishes are reapplied (de Freitas et al., 2011; Alfano, 2019).

2.4 Global and Regional Evidence of Dampness Prevalence

Prevalence studies outside the tropics consistently find rising and penetrating damp as the leading categories in older masonry stock (Becher, 2017; Hall et al., 2011), while condensation dominates in tightly sealed, poorly ventilated modern buildings in temperate climates (Salonen, Bornehag & Sundell, 2013). Within Sub-Saharan Africa and South-East Asia, case evidence points toward penetrating and rising damp as the dominant mechanisms in both residential and institutional buildings: Halim and Halim (2010) and Halim, Harun and Hamid (2012) report similar patterns in Malaysian heritage buildings; Othman (2015) documents moisture-related defects in Malaysian residential stock; and Kong, Sun, Weschler and Sundell (2018) report widespread dampness problems in Tianjin dwellings, though driven by different climatic mechanisms. In Nigeria specifically, Sani (2022) reports significant rising and penetrating damp in residential buildings in Kaura-Namoda, Zamfara State, while Zakariyyah et al. (2020) documents dampness patterns in university halls of residence in Lagos, and Toyinbo (2019) provides one of the few indoor-environmental-quality pilot assessments of Nigerian primary schools.

Burkinshaw and Parrett's (2004) diagnostic guidance, though developed for UK building stock rather than tropical conditions specifically, sets out the staged visual-to-instrumented diagnostic logic that this paper's classification approach in Section 3.4 adapts to a tropical context, following a precedent for such adaptation already established in the regional literature (e.g., applications of the same framework to Ghanaian residential buildings). More recently, Sousa's (2024) systematic review of building characteristics as dampness indicators reinforces envelope condition and ventilation as the dominant explanatory variables across the international literature, while a 2026 mixed-methods study spanning Nigeria's coastal, semi-arid and tropical zones reports zone-specific pathology signatures, chloride-driven corrosion on the coast, thermal cracking in semi-arid areas, and biological colonisation in tropical zones, using the same chi-square and regression toolkit adopted in Section 3.5, and constitutes the most directly comparable recent Nigerian evidence base for this paper's zonal analysis (Edo et al., 2026). Complementing this, Gao et al. (2025) and Liu, Huang and Wang (2025) provide recent quantitative

modelling of hygrothermal envelope response and wind-driven rain performance across climatic zones, underscoring that envelope-level, mechanism-specific diagnosis, rather than climate-zone-level generalisation alone, is the direction current building pathology research is moving in internationally.

2.5 Determinants of Dampness Type in Tropical Climates

In tropical and sub-tropical settings, rain penetration and waterlogging are reported as dominant mechanisms because of high rainfall intensity and, in many locations, shallow groundwater tables (Amadi & Higham, 2020; Agyekum & Ayarkwa, 2014). Studies from Ghana similarly report that older buildings with weakened roofing elements are disproportionately prone to penetrating damp (Agyekum & Koranteng, 2014; Asamoah & Ofei-Nyako, 2017), while buildings situated on waterlogged or poorly drained sites are prone to rising damp irrespective of age (Ibitayo & Ogunoh, 2020). Corrugated-metal roofing, the dominant roof covering in Nigerian public-school construction, is particularly susceptible to two degradation processes that elevate penetrating-damp risk over time: ultraviolet and thermal cycling degrade fastener washers and sealant at penetration points, and corrosion of the fasteners themselves loosens the mechanical fixing and opens capillary paths at lap joints (Ishak & Kayan, 2013; Oliver, 1988). Gana (2015) similarly links dampness prevalence in high-rise buildings to site drainage and construction quality rather than climate alone, suggesting that within a broadly humid or wet-tropical macro-climate, local site, roofing-material condition, and construction-detailing factors, rather than regional rainfall averages alone, may be the more proximate determinant of which damp type predominates at a given location.

2.6 Research Gap and Contribution

Three gaps motivate this paper. First, comparatively little of the tropical dampness literature focuses specifically on public school buildings in Nigeria's North-East, a region with distinct rainfall seasonality and building-stock characteristics relative to the southern and coastal contexts more commonly studied (Agyekum & Ayarkwa, 2014; Amadi & Higham, 2020). Second, much of the existing regional evidence is descriptive or single-site, reporting prevalence without formally testing whether damp-type distribution varies by location, a distinction with direct practical consequences, since a statistically confirmed zonal difference justifies zone-specific intervention, whereas a non-significant difference does not. Third, and most significantly for its positioning as a building pathology contribution, prevalence documentation in this regional literature is rarely connected back to the moisture-transport and material-degradation mechanisms reviewed in Sections 2.2 and 2.3; this paper explicitly makes that connection, reframing its contribution from documentation of what is present toward diagnostic insight into why the observed pattern of damp types is physically consistent with the construction characteristics of this specific building stock.

3. Materials and Methods

3.1 Study Design

This is a cross-sectional observational study, recording the physical condition of sampled buildings at a single point in time rather than tracking change over a period. This design is appropriate to the paper's diagnostic aim, establishing which damp types are present and how they are distributed, but it cannot establish causal direction or capture seasonal variation in condensation or rain-penetration severity; a single dry- or wet-season visit could under- or over-represent condensation and penetrating-damp indicators respectively, a limitation returned to in Section 3.6. The study was conducted in Adamawa State, located in the North-Eastern zone of Nigeria, across its five educational zones: Ganye, Yola, Mubi, Numan and Gombi.

3.2 Sampling Frame and Population

Grade-A public secondary schools in Adamawa State are defined by the state Ministry of Education's own institutional stratification of its secondary school stock: mega boarding schools established before 1976, distinguished from Grade-B and later-established institutions by scale, facility provision, and founding date. By this official classification, the population comprises exactly ten such schools statewide, two in each of the state's five educational zones. This study therefore constitutes a complete census of all Grade-A public secondary schools in Adamawa State, all ten eligible institutions were included, rather than a probability sample drawn from a larger population of Grade-A institutions; no school-level sampling error is therefore introduced at this level, though external validity beyond the Grade-A category (for example, to Grade-B or more recently constructed schools) is correspondingly not established and is flagged again in Section 6. Within this fixed frame, one urban and one semi-urban Grade-A school were included per zone, so that stratification by settlement type (urban/semi-urban) was applied to select which of the ten fixed institutions to visit, not to draw a subsample from a larger frame. Site-level respondents (90 in total: 10 principals, 20 vice-principals, 60 works-department staff) were selected within each school using purposive sampling (by role) and simple random sampling (among eligible staff in each role), reported in full in the companion questionnaire-based papers from this research programme. The typology data reported in this paper derive from the observational checklist applied at all ten census schools, not from the staff questionnaire.

3.3 Instrumentation

A structured observational checklist, developed in line with the study's diagnostic objective, was used by the researcher to record the type and severity of dampness present at each site. The checklist underwent face and content validation by three lecturers in the Department of Technology Education, Modibbo Adama University, who reviewed item suitability against the research aims (face validity) and coverage of the construct being measured (content validity); items were revised in line with their comments before use. A structured questionnaire administered separately, addressing the study's structural stability, causes and mitigation research questions (reported in companion papers from this research programme), was piloted on ninety respondents in five Grade-B secondary schools not part of the study population, yielding a Cronbach alpha coefficient of 0.87 for that instrument's internal consistency. That reliability coefficient applies to the Likert-type questionnaire and is reported here for completeness; it is not a property of the present paper's observational checklist, and no internal-

consistency statistic is claimed for the checklist itself, consistent with standard practice, since Cronbach's alpha is designed for multi-item attitudinal scales rather than presence/absence diagnostic recording.

3.4 Diagnostic Classification Protocol

Each recorded damp case was assigned to one of the three types using visual indicator criteria consistent with established building pathology diagnostic guidance for tropical and temperate buildings alike (BRE Digest 245: Trotman, 2007; Burkinshaw & Parrett, 2004; Riley & Cotgrave, 2005). Rising damp was identified by a tide-mark pattern and powdery salt efflorescence concentrated at low wall level, generally not exceeding approximately 1.0-1.5 m in height, unrelated to recent rainfall events, and typically co-located with crumbling plaster and paint failure at the base of external and internal masonry (Gana, 2015; Hall et al., 2011). Consistent with BRE guidance that a positive moisture-meter reading alone is not conclusive evidence of active rising damp, since old salt accumulation can persist in walls without a current damp problem (Trotman, 2007), the checklist required the combined presence of tide-marking, efflorescence, and low-level concentration before a case was classified as rising damp, rather than relying on any single indicator. Penetrating damp was identified by staining or moisture patterns correlated with rainfall events, concentrated near roof-wall junctions, window and door reveals, parapets, and visible cracks, independent of height above ground (Laeirj, Spence & Laycock, 2013; Ishak & Kayan, 2013). Condensation damp was identified by surface moisture, mould growth, or discoloration at thermal bridges, uninsulated lintels, corners, and poorly ventilated rooms, following a transient, humidity- and occupancy-linked pattern rather than a fixed structural location (Mumovic et al., 2006; Evrard & De Herde, 2010). Where a site displayed indicators consistent with more than one mechanism, the checklist recorded the predominant, most visually developed indicator pattern as the classified type for that case. This design choice has a direct analytical consequence flagged here for clarity: the resulting dataset is structurally mutually exclusive, every case carries exactly one recorded type, so any statement made later in this paper about mechanism co-occurrence is necessarily an inference from indirect evidence (overlapping prevalence intervals, shared physical wetting pathways) rather than a direct measurement, since the data structure itself cannot represent a case as belonging to two categories at once. The primary safeguard against classification drift was the use of these fixed, operationally explicit criteria, height threshold, rainfall correlation, and structural location, applied uniformly by the same observer across all ten sites, rather than an unstructured visual impression; no formal periodic re-scoring or blind re-classification of earlier sites against later ones was conducted, however, and this remains a real limitation rather than a solved problem, addressed only partially here and more directly by the second-rater recommendation in Section 8.

3.5 Statistical Analysis

Checklist frequencies were first summarised as descriptive percentages by zone and by urban/semi-urban location. To test whether the distribution of damp type varied systematically across categorical groupings, two Pearson chi-square tests of independence were conducted on the contingency tables of (i) zone x damp type (5 x 3) and (ii) location type x damp type (2 x 3), using a significance threshold of

alpha = 0.05. Cramer's V was computed as a standardised effect-size measure alongside each test, since chi-square significance alone does not indicate association strength. The chi-square approximation is valid only when expected cell frequencies are not too small; for both contingency tables in this study, all expected cell frequencies exceeded the conventional minimum threshold of 5 (zone x type: minimum expected count = 6.42; location x type: minimum expected count = 16.49), so no continuity correction or exact test (e.g., Fisher's exact test) was required. All statistical computation was performed in Python (SciPy 1.x); descriptive summaries were cross-checked in Microsoft Excel and SPSS, consistent with the study's original data-processing pipeline.

3.6 Methodological Limitations and Diagnostic Validity

Three limitations bear directly on diagnostic validity and are stated explicitly rather than left implicit. First, classification followed the visual protocol in Section 3.4 without instrumental triangulation: no electrical-resistance or capacitance moisture-meter readings, relative-humidity/temperature logging, or thermal imaging were used to corroborate visual classification or to detect interstitial condensation that produces no external visual signature. Visual diagnosis of this kind is standard in tropical building condition surveys of this scale (Burkinshaw & Parrett, 2004) but is acknowledged here as a lower evidentiary tier than instrumented diagnosis, and Section 8 recommends instrumented validation as a direct next step. Second, the checklist was applied by a single trained observer; while the visual criteria in Section 3.4 were designed to be as operationally explicit as possible to constrain subjective judgement, no second-rater scoring was conducted, and an inter-rater reliability statistic (such as Cohen's kappa) is consequently not available for this dataset. Third, the cross-sectional, single-visit design (Section 3.1) means prevalence figures reflect conditions at one point in the rainfall calendar; condensation prevalence is plausibly sensitive to the season of inspection, and the 12.6% figure reported here should be read as a single-timepoint estimate rather than an annual average. All three limitations affect precision at the margins of ambiguous, mixed-indicator, or seasonally borderline cases rather than the overall typological pattern, which is broad enough (278 cases, clear indicator separation between types, effect sizes reported with confidence intervals) that misclassification of individual borderline cases is unlikely to reverse the study's principal findings.

4. Results

4.1 Overall Typology Distribution

Table 1
Frequency of Dampness Cases by Educational Zone and School Setting (Counts)

Zone	School (Setting)	Rising (n)	Condensation (n)	Penetrating (n)	Row Total (n)
Yola	GMMC Yola (Urban)	7	1	14	22
Yola	GGSS Girie (Semi-urban)	11	2	18	31
Mubi	GSTC Mubi (Urban)	13	3	15	31
Mubi	GSS Uba (Semi-urban)	14	2	16	32
Gombi	GSS Hong (Urban)	11	3	11	25
Gombi	GSS Gombi (Semi-urban)	13	4	13	30
Numan	GSTC Numan (Urban)	11	5	12	28
Numan	GSS Villanova (Semi-urban)	14	1	13	28
Ganye	GSS Sugu (Urban)	9	3	13	25
Ganye	GSS Mayo (Semi-urban)	7	11	8	26
Column Total	(10 schools)	110	35	133	278

Table 2
Overall Prevalence of Dampness Types with 95% Wilson Confidence Intervals

Damp Type	Frequency (n)	% of Total (N = 278)	95% Wilson CI
Penetrating damp	133	47.8%	[42.0%, 53.7%]
Rising damp	110	39.6%	[34.0%, 45.4%]
Condensation	35	12.6%	[9.2%, 17.0%]
Total	278	100.0%	-

Table 1, Table 2, and Fig. 1 show that penetrating dampness is the most frequently observed type across the sampled buildings, accounting for 133 of 278 total cases (47.8%, 95% Wilson CI [42.0%, 53.7%]), followed by rising dampness at 110 cases (39.6%, 95% CI [34.0%, 45.4%]); condensation dampness was the least prevalent type at 35 cases (12.6%, 95% CI [9.2%, 17.0%]). The confidence intervals for rising and penetrating damp overlap, indicating that while penetrating damp has the higher point estimate, the two leading mechanisms are not sharply separated at this sample size; condensation's interval is clearly non-overlapping with the other two, confirming it as the distinctly least prevalent type rather than merely the

lowest-ranked of three similar values. Read against the diagnostic criteria in Section 3.4, this distribution is dominated by rainfall-correlated, entry-point-driven staining rather than height-limited, ground-linked tide-marking, a pattern developed further in Section 5.

4.2 Zonal Distribution

Aggregated by zone, Mubi recorded the highest overall prevalence of dampness (23.0% of all cases), followed by Numan (21.4%), Gombi (19.8%), Yola (19.1%) and Ganye (18.3%). Figure 2 shows that this ranking is driven primarily by penetrating and rising damp counts rather than condensation, which remained a comparatively minor contributor in every zone except Ganye, where the semi-urban school (GSS Mayo) recorded 11 condensation cases against single figures everywhere else in the sample, a clear outlier worth addressing directly rather than passing over. This concentration is unlikely to reflect simple recording drift, since the same observer applied the same fixed criteria (Section 3.4) uniformly across all ten sites; a single site producing an outlying count under a consistent protocol more plausibly reflects a genuine local condition specific to that building, such as denser tree cover, more sheltered siting, or comparatively poorer cross-ventilation than the other nine schools, than an artefact of measurement. However, the study did not collect the site-level shading, ventilation, or occupancy-density data that would be needed to confirm any specific explanation, so this remains reported here as an unexplained zonal concentration rather than a resolved one, and is flagged as a specific candidate for the instrumented follow-up recommended in Section 8.

4.3 Urban Versus Semi-Urban Composition

In absolute terms, semi-urban schools recorded a higher overall incidence of dampness (147 of 278 cases, 52.9%) than urban schools (131 cases, 47.1%). However, as Fig. 3 shows, the proportional mix of damp types is nearly identical between the two settings (urban: 39% rising, 11% condensation, 50% penetrating; semi-urban: 40% rising, 14% condensation, 46% penetrating), the difference lies in total case volume, not in which mechanism dominates.

4.4 Statistical Tests of Association

Table 3
Chi-Square Tests of Association Between Damp Type and Categorical Predictors

Test	Chi-sq	df	p-value	Cramer's V	Interpretation
Zone x Damp type (5x3)	16.82	8	0.032	0.17	Significant; weak-to-moderate association
Location x Damp type (2x3)	0.44	2	0.801	0.04	Not significant; negligible association

The chi-square test of independence confirms that damp-type distribution differs significantly across the five educational zones (chi-square = 16.82, df = 8, p = 0.032), though the Cramer's V of 0.17 indicates the association is weak-to-moderate in strength rather than a dominant explanatory factor on its own. By

contrast, the location-type test is not statistically significant (chi-square = 0.44, df = 2, p = 0.801, Cramer's V = 0.04), indicating that while semi-urban schools carry a higher absolute case burden, the underlying mechanism mix does not differ meaningfully between urban and semi-urban settings in this sample.

5. Discussion

5.1 Why Penetrating Damp Predominates: A Mechanism-Level Reading

The dominance of penetrating dampness is not simply a descriptive finding but is physically consistent with the roofing technology and construction detailing typical of this building stock. Corrugated-metal roofing, near-universal in Nigerian public school construction, is vulnerable to two compounding degradation processes over a multi-decade service life: ultraviolet and thermal cycling embrittle fastener washers and sealant, and electrochemical corrosion of the fasteners themselves loosens their mechanical grip, opening capillary entry paths at lap joints exactly where wind-driven rain load is highest during tropical convective storms (Ishak & Kayan, 2013; Oliver, 1988; Amadi & Higham, 2020).

This is consistent with reports that older buildings with weakened or poorly maintained roofing are disproportionately susceptible to rain penetration (Agyekum & Koranteng, 2014). Because penetrating damp is considered particularly damaging to a building's life-span (Oliver, 1988), and because it enters at the roof-wall junction and propagates downward and inward through the building fabric, its predominance in this sample is a diagnostic signal that roofing condition and flashing detail, rather than ground moisture alone, should be the first point of inspection in this building stock, a conclusion the visual pattern in Section 3.4 supports directly, since penetrating-damp indicators concentrated at junctions and openings rather than at uniform low-wall height. The overlapping confidence intervals for penetrating and rising damp noted in Section 4.1 are consistent with this mechanism-level reading rather than undermining it: because a leaking roof-wall junction wets the same masonry that is independently susceptible to capillary rise, some proportion of the 278 recorded cases plausibly reflect co-occurring rather than mutually exclusive mechanisms, and the checklist's predominant-indicator rule (Section 3.4) would classify such mixed cases under whichever pattern was most visually developed at the time of inspection. It is important to be precise about what this claim is and is not: co-occurrence is inferred from the statistical pattern (overlapping intervals) and from the physical plausibility of shared wetting pathways, not from a direct count of sites exhibiting multiple simultaneous indicators sets, since the single-category recording protocol did not capture secondary indicators once a predominant type was assigned.

The forced single-category classification therefore likely masks some mixed-mechanism cases rather than eliminating them, which would tend to inflate the apparent separation between categories rather than create false overlap, meaning the true extent of mechanism co-occurrence in this building stock is probably underestimated, not overestimated, by the figures in Table 1. Resolving this precisely requires the instrumented, multi-indicator recording protocol recommended in Section 8, rather than further

reanalysis of the present visual dataset. This has a direct consequence for material degradation: following the pathway set out in Section 2.3, sustained penetrating-damp wetting at roof-wall junctions and lintels drives the same salt-crystallisation and corrosion mechanisms, mortar loss, metal-frame corrosion and spalling, that the companion structural-stability analysis in this research programme records as the most severe impact indicators in this building stock, linking the typological pattern reported here directly to structural risk rather than leaving it as a surface-level classification exercise.

5.2 Rising Damp: Capillary Mechanics and the Zonal Pattern

The secondary prevalence of rising dampness is explicable through the capillary mechanics reviewed in Section 2.2: buildings situated in waterlogged environments, common in parts of Nigeria, are structurally predisposed to capillary moisture rise wherever an effective damp-proof membrane is absent or has been bridged (Amadi & Higham, 2020; Ibitayo & Ogunoh, 2020). The statistically significant zonal difference (Section 4.4) reinforces that this is not uniform across the state: Mubi and Numan zones carry a disproportionate share of cases, plausibly associated with comparatively higher annual rainfall frequency in Mubi zone relative to the other four zones (Weather Watch, 2023), consistent with Gana's (2015) observation that local site and drainage conditions, layered onto regional climate, shape which damp mechanism predominates and at what rate capillary rise reaches its evaporation-limited maximum height. This remains an association rather than a tested causal claim within the scope of this diagnostic study; rainfall, soil, and drainage data were not directly modelled as covariates here. Structurally, the consequence of sustained capillary rise is the same salt-driven mortar and plaster degradation pathway detailed in Section 2.3: as the evaporation front cycles with each wetting episode, dissolved ground salts recrystallise within the pore structure of low-level masonry, and it is this recrystallisation pressure, not the moisture itself, that produces the crumbling plaster and base-of-wall material loss recorded as a severe structural stability impact in the companion analysis, reinforcing that rising damp's zonal pattern is not merely a distributional curiosity but a proxy for where this degradation pathway is currently most active.

5.3 Condensation, the Urban/Semi-Urban Null Result, and International Comparison

Condensation's comparatively low prevalence departs from patterns reported in temperate climates, where tightly sealed, poorly ventilated modern buildings show condensation as a leading damp category (Salonen, Bornehag & Sundell, 2013). This divergence is consistent with the school buildings in this sample being naturally, rather than mechanically, ventilated, and with the tropical climate sustaining warmer ambient and surface temperatures that keep them further from dew point for more of the year than temperate-climate buildings, though, as Section 3.6 notes, this study's visual-only protocol cannot rule out undetected interstitial condensation, which is a plausible explanation for at least part of the unexplained residual in the zonal chi-square test. The non-significant urban/semi-urban test is, in some respects, the more practically important finding of the study. A naive reading of the raw totals, semi-

urban schools recording more cases, might suggest that urban and semi-urban buildings face qualitatively different damp problems requiring different remediation strategies.

The chi-square result indicates otherwise: the mechanism mix is statistically indistinguishable between settings, so the appropriate response to the semi-urban case-volume gap is more of the same intervention (roof and envelope repair, DPM installation), not a setting-specific diagnostic protocol. This pattern, volume differing while mechanism mix remains stable, has, to the authors' knowledge, not been explicitly tested in the regional tropical dampness literature reviewed in Section 2.4, which typically reports prevalence without this distributional test, and is offered here as a transferable methodological point for comparable tropical building-stock surveys. Where condensation does occur, its structural consequence follows a different pathway from the other two mechanisms: sustained surface moisture at cold bridges creates conditions for mould growth and, on timber components specifically, for fungal decay and secondary termite infestation (Section 2.3), which the companion structural-stability analysis records among its most severe impact indicators despite condensation being the least prevalent damp type overall, a reminder that prevalence and structural consequence are not the same axis, and that a low-frequency mechanism can still warrant monitoring disproportionate to its case count.

5.4 From Typology to Structural Risk: Why Mechanism, Not Just Presence, Matters

Within this research programme, structural stability is operationalised through a fixed set of measurable degradation indicators, masonry cracking severity, wall-surface spalling and mortar loss, corrosion extent on embedded and exposed metal frames, and timber decay/warping severity, each rated on a five-point severity scale in the companion structural-stability analysis, rather than treated as a single undifferentiated construct. The three mechanism-level readings above (Sections 5.1–5.3) converge on a single point with direct bearing on this operational definition of structural stability: dampness typology is not an end but the diagnostic front end of a material degradation and structural risk pathway.

Penetrating damp's predominance points toward roof-junction and lintel wetting driving mortar loss and metal corrosion; rising damp's zonal concentration points toward salt-crystallisation-driven masonry degradation at low wall level; and condensation, though least prevalent, points toward a disproportionate timber-decay and termite risk at cold bridges. Each of these degradation pathways corresponds to a specific structural stability impact indicator, wall cracking, corroded metal frames, and timber decay respectively, independently rated as severe-to-very-severe in the companion structural-stability analysis of this research programme. The practical implication is that the typological diagnosis performed in this paper is not merely descriptive groundwork: it identifies which structural degradation pathway is currently most active at a given site, and therefore which structural stability indicators an inspector should prioritise checking first. This paper's scope and its limit should both be stated plainly: it establishes the diagnostic and mechanistic basis of deterioration, what type of dampness is present, where, and by what physical pathway it damages materials, while direct measurement of structural stability severity across this same building stock is presented in the companion study, which this paper

does not duplicate or substitute for. This is the paper's central bridge to Paper 2 of this research programme, which quantifies the structural stability consequence directly.

6. Contribution to Knowledge

This study's contribution is not simply the documentation of dampness types and their distribution in Adamawa State's public secondary schools. It is, first, a mechanism-linked diagnostic account that connects observed typological prevalence to the specific moisture-transport pathways (capillary suction, wind-driven rain, vapour condensation) and material-degradation consequences (salt-driven mortar loss, metal corrosion and spalling, timber fungal decay) reviewed in Sections 2.2 and 2.3, rather than reporting prevalence as an endpoint. Second, it is a statistically tested zonal and settlement-type baseline, using chi-square association testing not previously applied to this specific regional building stock and typological question, which distinguishes a genuine geographic pattern (zone) from an apparent but statistically unsupported one (urban/semi-urban). Third, it is an explicit diagnostic protocol (Section 3.4) that can be reapplied, tested, and refined by subsequent researchers working in comparable tropical, resource-constrained public infrastructure settings, addressing the scarcity of climate-specific diagnostic guidance noted in Section 2.4.

7. Practical and Policy Implications

For state ministries of education and school facility managers operating under constrained maintenance budgets, three implications follow directly from the findings. First, routine building condition audits in this and comparable tropical settings should prioritise roof and envelope inspection, specifically fastener corrosion, sealant condition, and flashing details at roof-wall junctions, before considering ground-moisture interventions, since penetrating damp is both the most prevalent type and, per the mechanism review in Section 5.1, the most structurally consequential. Second, the statistically confirmed zonal difference supports geographically targeted resource allocation, with Mubi and Numan zones warranting closer monitoring cycles than Ganye. Third, because damp-type mix does not differ meaningfully between urban and semi-urban schools, a single standardised maintenance protocol, rather than separate urban and semi-urban guidance, is statistically justified for this building stock, simplifying implementation for a resource-limited administering authority.

8. Conclusion and Recommendations for Future Research

This study establishes a statistically grounded, pathway-aware, zone-disaggregated diagnostic baseline for dampness typology in public secondary school buildings in a tropical Nigerian state. Penetrating dampness predominates, followed by rising dampness, with condensation the least prevalent type; the pattern is physically consistent with wind-driven rain ingress through a degrading corrugated-roof envelope rather than with capillary ground moisture as the primary driver; the zonal distribution of damp type is statistically significant, while the urban/semi-urban distribution is not. Misdiagnosing the dominant damp mechanism at a given site risks directing limited maintenance budgets at the wrong

remediation, making correct, mechanism-aware typological diagnosis, not just awareness that dampness exists, the necessary first step for any intervention in this setting.

Three takeaways follow directly. Technically, roof envelope condition (fastener integrity, flashing detail, sealant degradation) is the priority diagnostic target in this building stock, ahead of ground-moisture and damp-proof-membrane inspection, because penetrating damp both predominates and, per Section 5.1, causes disproportionate structural consequence. For policy, the statistically confirmed zonal difference justifies a differentiated maintenance-funding formula across Adamawa State's educational zones rather than a uniform per-school allocation, with Mubi and Numan zones prioritised. For research, the clearest next step is instrumented validation of the visual diagnostic protocol used here (Section 3.6), since the field's credibility as diagnostic building pathology, rather than descriptive survey work, depends on closing that evidentiary gap.

Future work should:

- (i) instrument a representative subsample of sites with electrical-resistance or capacitance moisture meters, relative-humidity/temperature logging, and thermal imaging to triangulate the visual classification protocol in Section 3.4 and directly test for undetected interstitial condensation;
- (ii) extend the diagnostic approach to a larger, non-Grade-A school sample, with a second independent rater to permit calculation of inter-rater reliability (e.g., Cohen's kappa);
- (iii) directly model zone-level rainfall, soil, and building-age data as predictors of damp type and severity using regression techniques, building on the associations identified here and on recent Nigerian precedent for this analytical approach (Edo et al., 2026); and
- (iv) pair this typological baseline with the companion analyses of structural stability impact and cause-matched mitigation strategy reported elsewhere in this research programme, to test whether damp type, not just damp presence, predicts structural severity.

Declarations

Conflict of Interest

The author(s) declare no conflict of interest.

Ethics Approval

Institutional observation of public buildings was conducted with the permission of the relevant school authorities and Adamawa State Ministry of Education. No human subject's data requiring formal ethics board clearance were collected in the checklist component reported in this paper.

Acknowledgment of Generative AI Use

During the preparation of this manuscript, the authors used generative artificial intelligence tools, including Claude AI (Anthropic), ChatGPT (OpenAI), DeepSeek, QuillBot, and Elicit, in a strictly supportive and non-authorial capacity. These tools were employed to assist with language refinement (grammar, clarity, and academic tone), literature-screening support, and formatting consistency checks. No generative AI tool was used to generate, fabricate, or alter research data, statistical results, or substantive scientific conclusions. All data collection, diagnostic classification, statistical analysis, and interpretation reported in this study were conducted independently by the authors. Every AI-assisted output was critically reviewed, verified against primary sources, and revised by the authors, who take full responsibility for the accuracy, originality, and scholarly integrity of the final manuscript. The use of these tools complied with the ethical guidelines on AI-assisted writing issued by the journal or publisher, as well as the authors' institutional research-integrity policies. No AI tool is credited as an author, in accordance with prevailing authorship criteria, which require accountability for the work, a capacity generative AI system does not possess.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contribution

Conceptualisation, methodology, data collection, formal analysis, and writing, original draft: Joseph Philip Gassa. Data collection, formal analysis: Kabiru Maiungwa

Acknowledgements

The author thanks the principals, vice-principals and works-department staff of the ten sampled schools for facilitating site access, and the validating lecturers who reviewed the study instrument.

Data Availability Statement

The checklist dataset summarised in Table 1 is available from the corresponding author upon reasonable request.

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Figures

Overall Distribution of Dampness Types (N = 278 recorded cases)

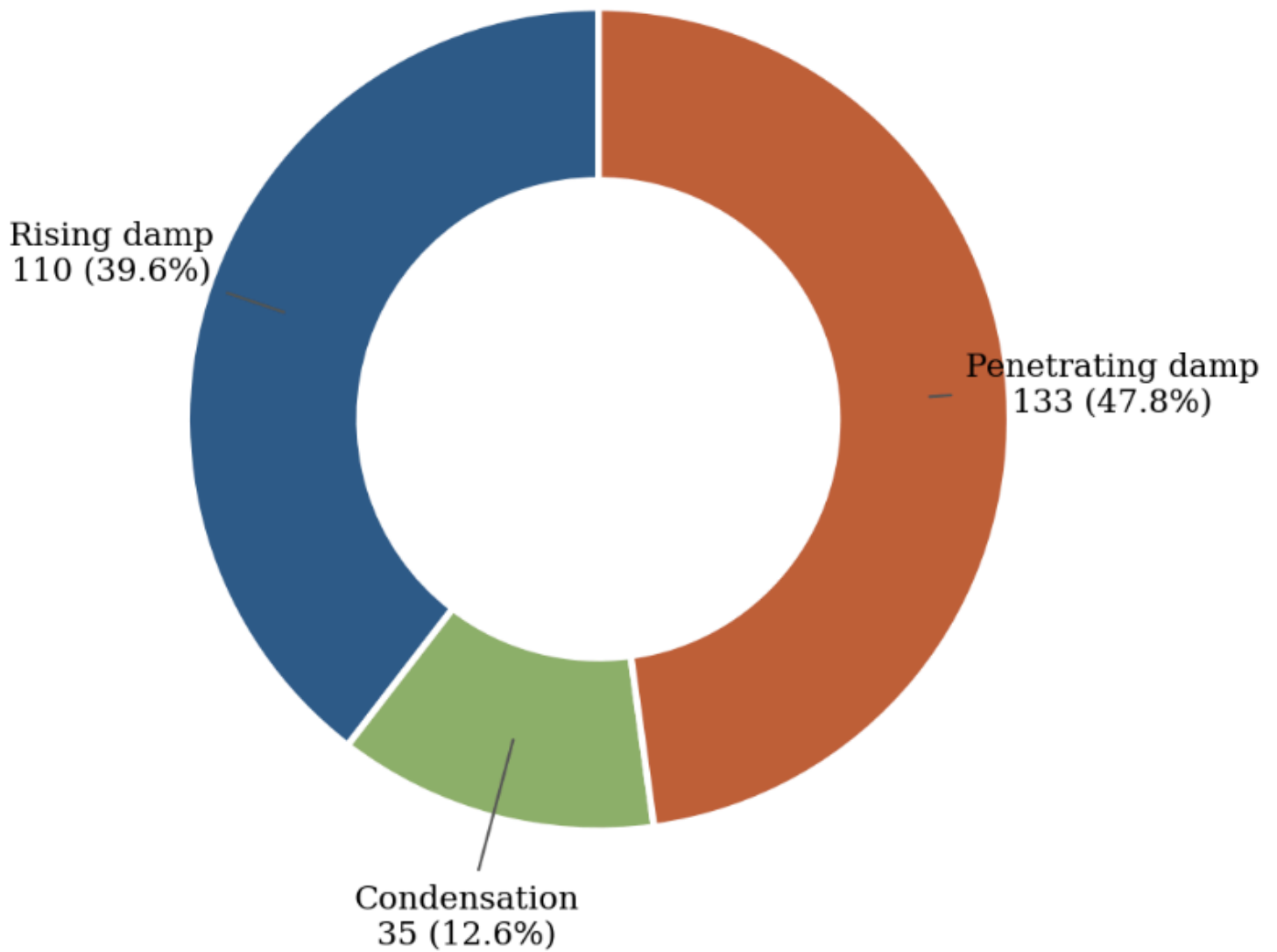


Figure 1

Overall distribution of dampness types across all sampled buildings (N = 278).

Distribution of Dampness Types Across the Five Educational Zones of Adamawa State

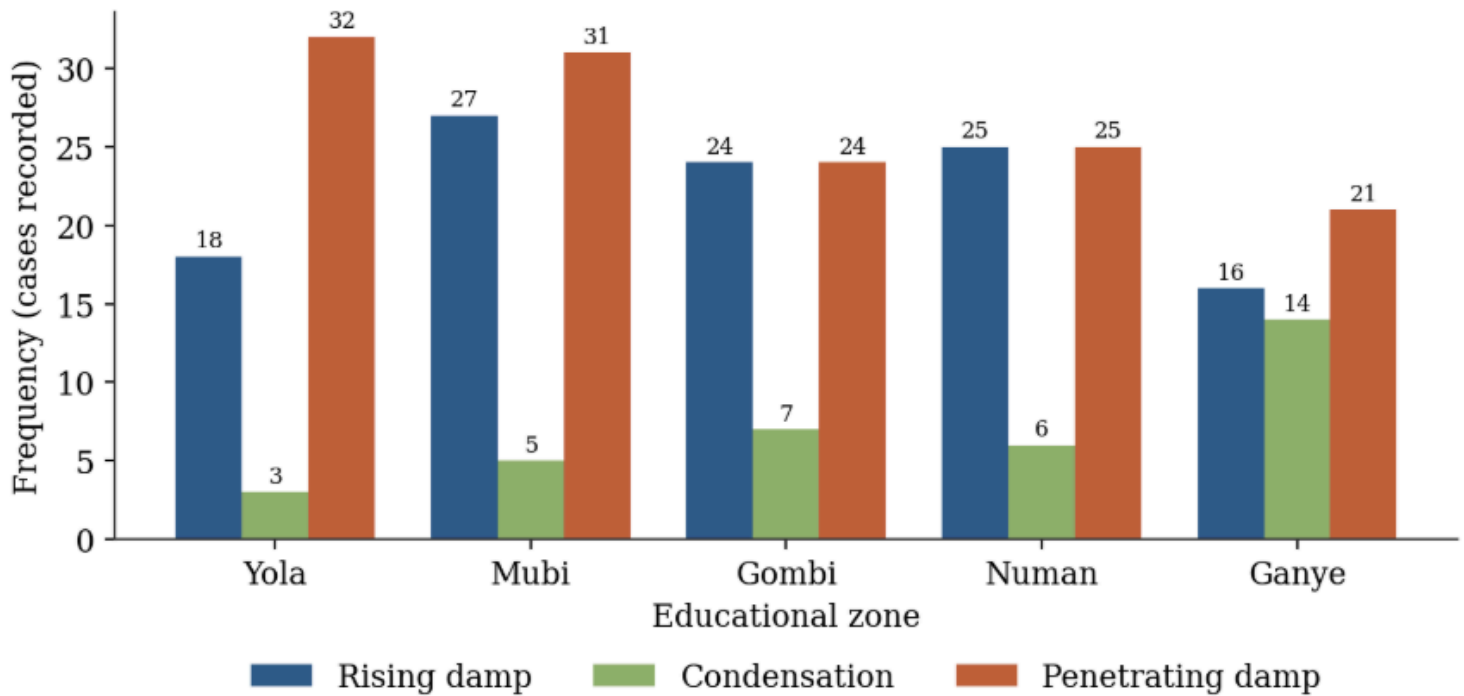


Figure 2

Frequency of each dampness type by educational zone.

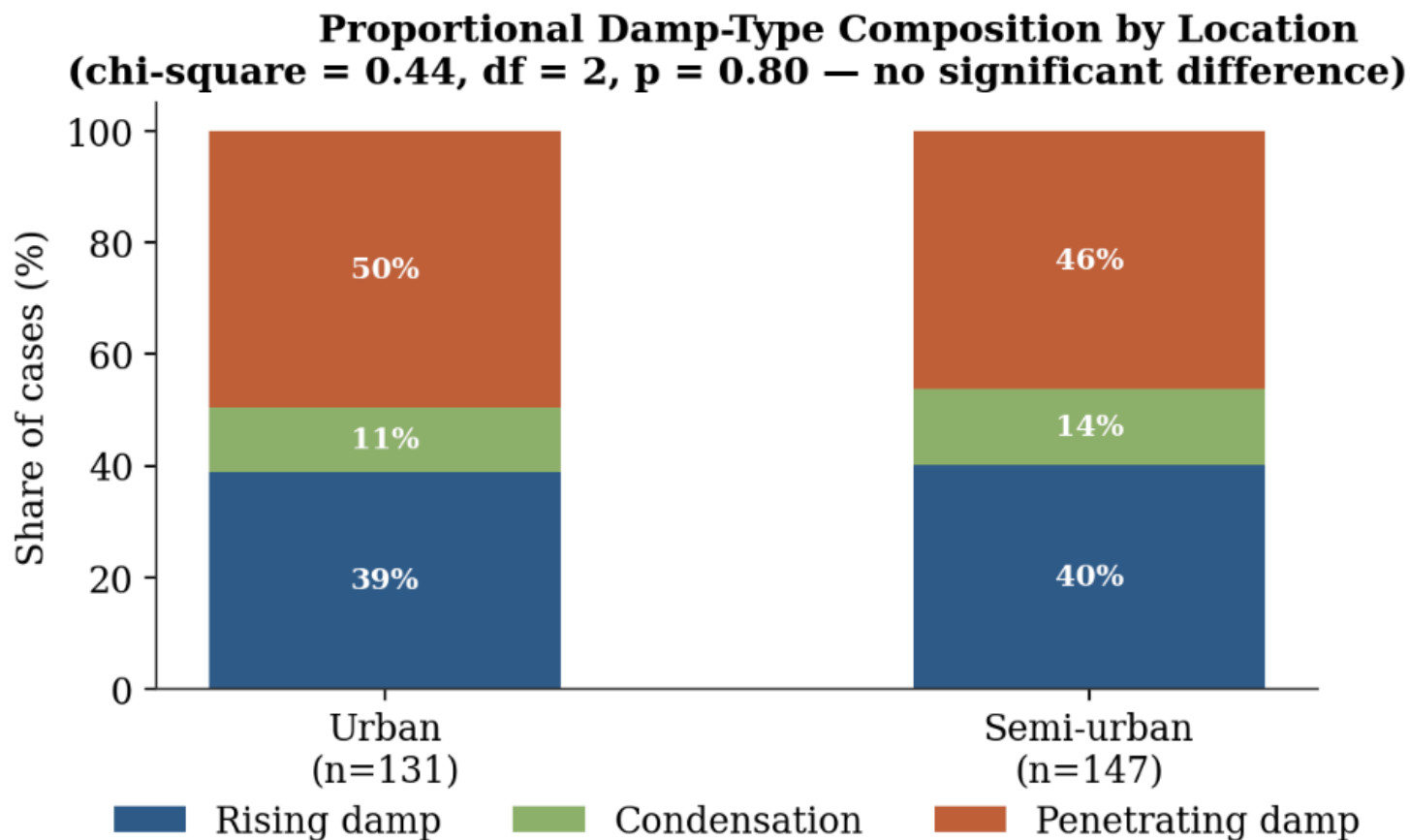


Figure 3

Proportional composition of dampness type by location setting (urban vs semi-urban).