



Received: 19-08-2026
Accepted: 29-09-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Classroom Heat Exposure, Lesson Timing and Learning Outcomes in Rural Namibian Primary Schools: An Integrative Narrative Review and Field Evaluation Framework

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Abstract

Classroom heat can undermine the conditions needed for learning even when schools remain open. This review examines how indoor temperature, lesson timing, ventilation and task difficulty should be considered together when evaluating learning outcomes in rural Namibian primary schools. A targeted narrative search identified classroom intervention studies, longitudinal achievement analyses, recent Southern African environmental and health studies, and climate education reports. Evidence was organised by exposure measurement, outcome type and relevance to naturally ventilated schools. Experimental findings support improvements in the speed of some school tasks under cooler conditions, whereas longitudinal studies associate repeated hot school days with weaker learning. However, these outcomes are not interchangeable, and available evidence does not establish a universal classroom

temperature threshold or the effectiveness of low-cost adaptations in rural Namibia. A field evaluation framework is therefore developed around continuous environmental monitoring, equivalent short assessments, delayed retention tests and balanced allocation of lessons across time periods. Candidate adaptations include external shade, context-sensitive ventilation and timetable changes that preserve instructional time. The analysis emphasises confounding by clock time, task difficulty, attendance and classroom characteristics, and separates total intervention effects from changes mediated through temperature. Locally evaluated combinations of building and teaching adaptations could support climate-resilient education, but their learning benefits, affordability and equity implications require prospective testing.

Keywords: Classroom Heat, Lesson Timing, Learning Outcomes, Rural Primary Schools, Climate Adaptation

Introduction

Heat exposure is an education problem as well as a building and public health problem. UNICEF estimated that climate hazards disrupted schooling for at least 242 million students in 85 countries or territories during 2024, with heatwaves affecting an estimated 171 million students ^[1]. These figures describe interruptions to schooling, rather than measured losses in classroom learning. A complementary concern is what happens on hot days when schools remain open and pupils continue working in uncomfortable rooms.

Namibia provides a relevant setting for examining this concern. Its climate risk profile identifies rising temperatures and exposure to climate variability as development challenges ^[2]. National climate information, however, cannot establish the conditions inside an individual classroom. Roof construction, orientation, shade, occupancy, window operation and local weather can produce different exposures within the same school. Consequently, weather-station temperature should provide context rather than replace measurements where pupils sit.

Classroom experiments have investigated temperature and ventilation using repeated school tasks ^[3, 4], while a synthesis of temperature studies has identified relationships between thermal conditions and performance ^[5]. Larger achievement studies link hot school days to slower learning ^[6, 7]. More recent South African work demonstrates the feasibility of repeated environmental measurement and documents differences between classroom building types ^[8, 9]. A 2025 study of primary-school children in Gauteng also examined heat-related symptoms ^[10]. Together, these sources justify investigation while leaving important questions about practical implementation in rural Namibia.

Three distinctions organise the present review. First, an immediate score can reflect the conditions of assessment as well as what a pupil has learned. Second, clock time is related to temperature but also to fatigue, breaks, hunger and the order of lessons. Third, subject labels do not adequately describe difficulty: both mathematics and reading contain routine and demanding tasks. A credible study therefore needs to measure indoor exposure, balance lessons across the timetable and classify task demands before comparing outcomes.

The contribution is an integrated framework for local evaluation, rather than a claim that heat and learning have never been studied. A recent African working paper examines temperature and primary learning across eight countries [11], and a 2026 systematic review addresses temperature-related academic outcomes [12]. The selected literature does not establish the joint effect of measured indoor heat, lesson timing, ventilation and calibrated task difficulty in rural Namibian primary classrooms. This article addresses that specific design problem by connecting building measurements, classroom assessment and feasible adaptation decisions.

The objectives are to synthesise the relevant evidence; distinguish immediate performance, retention and attendance outcomes; identify threats to inference about heat and lesson timing; and specify a reproducible framework for testing affordable adaptations. The central question is how schools can evaluate whether modifying the learning environment or timetable improves learning without reducing instructional time or excluding pupils who face travel and household constraints.

Materials and Methods

Review design and source identification

An integrative narrative review was undertaken using targeted web searches on 1 October 2026. Search phrases included “classroom temperature learning performance”, “classroom ventilation schoolwork children”, “heat and learning”, “South Africa classroom temperature primary schools”, and “temperature primary learning Africa”. Searches for Namibian climate context and UNICEF education reports complemented the academic searches. Publisher pages, bibliographic records, university research repositories and official report pages were consulted to verify study descriptions and reference details. The search was purposive and iterative; it was not a systematic database search or an exhaustive account of the literature.

Priority was given to studies involving school-aged children, measured classroom conditions, repeated environmental observations, educational outcomes or regional relevance. Classroom intervention and longitudinal achievement studies were retained to represent different forms of evidence. Recent African environmental studies and one clearly identified working paper were included to improve contextual relevance. General adult workplace findings were not used to estimate school effects. Where only a verified abstract or repository summary was accessible, interpretation was restricted to information reported there. No pooled effect estimate or formal risk-of-bias score was calculated.

Eight selected school-based empirical publications form the evidence synthesis. Companion environmental data [8] support the interpretation of the South African classroom study [9] and are not counted as an independent replication.

Earlier and recent reviews [5, 12] provide synthesis context; institutional reports [1, 2, 13] provide climate and education context. For each empirical publication, the extraction categories were setting, design, exposure measurement, outcome, principal finding and transferability limitation. Differences in outcome scale and exposure definition were preserved rather than converted into a single percentage learning loss.

Conceptual framework and analytical scope

Fig 1 represents hypothesised relationships that guide the proposed field evaluation. Outdoor conditions and classroom features determine indoor exposure; exposure may influence comfort, attention and performance. Repeated changes in instruction, participation or attendance may then affect retention. Lesson timing and task difficulty are treated as possible modifiers that require testing. Shade and ventilation act primarily on exposure, while timetable changes alter when pupils encounter particular tasks. The diagram is a conceptual contribution and contains no estimated Namibian effects.

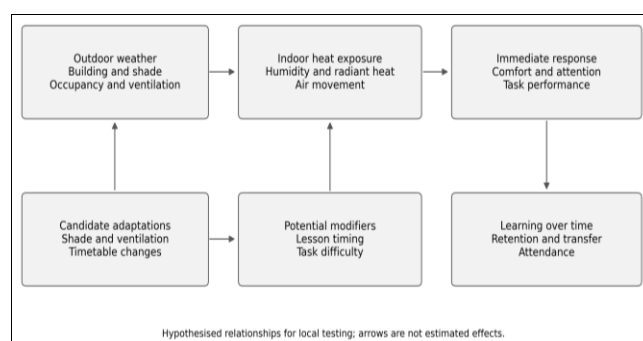


Fig 1: Conceptual relationships between classroom conditions, lesson allocation and learning. The arrows identify hypotheses for prospective evaluation, not demonstrated causal effects

The primary educational outcome proposed for local testing is performance on an equivalent short assessment after a defined lesson, with delayed retention assessed under comparable conditions. Task completion speed, accuracy, observed engagement and attendance are separate outcomes. Thermal comfort and heat-related symptoms inform interpretation and pupil welfare but are not substitutes for learning measures. The framework is intended for naturally ventilated classrooms and does not presume that mechanical cooling is available.

Proposed setting and participation

An initial evaluation could recruit rural primary schools in Kavango West and a contrasting inland region, with required permissions. Schools should be sampled by construction, shade and electricity access. Grades 4 to 7 offer a starting population for consistent short tasks and comfort questions. These are proposed settings; no recruitment has occurred. Findings would remain specific to sampled ages, buildings and seasons.

Eligible classrooms should have a stable teaching group, documented lesson times and a secure location for sensors. Children should participate only with required parental or caregiver consent and age-appropriate assent. Temporary absence should be recorded rather than used to remove a pupil from the cohort. A scheduled assessment should be classified as invalid if its lesson was cancelled, its timing

was undocumented or essential exposure records were lost. These exclusions should be determined from operational records before assessment results are inspected. Accessibility arrangements should support participation by pupils with disabilities.

Environmental measurement and quality assurance

Battery-powered temperature and relative-humidity loggers should record at five-minute intervals throughout occupied hours and, where possible, overnight. Sensors should be positioned near seated pupil height, protected from direct sunlight, water and tampering, and kept away from unusually local heat sources. Two locations per classroom are desirable where spatial differences are expected. A shaded outdoor logger provides local context. Clock settings should be checked against lesson records each week. Devices should be compared side by side before deployment and again afterwards to detect drift.

Temperature and humidity alone do not fully describe thermal exposure. If resources permit, globe temperature

and air speed should be measured during sampled lessons to characterise radiant conditions and air movement. Carbon dioxide measurements can provide an occupancy-related indicator of ventilation conditions, but they should not be reported as direct ventilation rates without an appropriate model and information about occupancy and outdoor concentrations. A low carbon dioxide reading also does not establish that a classroom is thermally comfortable. Window position, door position, fan operation, occupancy and shade should be recorded alongside each assessed lesson.

The measurement plan should specify allowable sensor uncertainty, calibration checks, download frequency, battery checks and procedures for missing intervals. A lesson exposure should be marked incomplete when more than a prespecified fraction of its measurements is missing; an initial operational rule could be 20%, subject to pilot review. Short internal gaps may be interpolated only under a documented rule and must be flagged. Entire hot lessons should never be reconstructed from daily averages. Table 1 summarises the linked records needed for analysis.

Table 1: Proposed variables and measurement schedule for a rural classroom evaluation

Domain	Measurement	Timing and interpretation
Indoor exposure	Air temperature and relative humidity; optional globe temperature and air speed	Five-minute logging; summarise separately for lesson, assessment and preceding occupied hours.
Ventilation context	Window and door position, occupancy, fan use; optional carbon dioxide	At each sampled lesson; carbon dioxide is not automatically an air-change rate.
Lesson allocation	Start and end times, subject, teacher, breaks and lesson content	Every assessed lesson; distinguish assigned from actual timetable.
Task demands	Equivalent forms, item content, difficulty and cognitive demand	Calibrate during pilot; retain form and item identifiers.
Learning	Immediate accuracy; delayed retention and transfer	After the lesson and approximately one week later under comparable conditions.
Participation	Attendance, missing assessments, engagement and brief comfort ratings	Daily attendance; lesson observations and age-appropriate ratings.
Implementation	Adaptation status, repair or installation cost, maintenance and instructional minutes	Record delivery throughout evaluation; calculate costs using local invoices or quotations.

Lessons and learning assessment

Curriculum-aligned assessments should be designed with local teachers and checked for language accessibility. Mathematics forms could include arithmetic fluency and multistep reasoning; language forms could include decoding and comprehension. Teachers should classify cognitive demand, and a separate pilot should estimate item difficulty. Forms should share anchor items or be equated using a suitable assessment model. A harder late-day form must not be mistaken for a temperature effect.

Assessments lasting approximately 8 to 12 minutes can be embedded in ordinary lessons, with the same time allowance across conditions. Accuracy should be scored against the total number of assigned items; attempted-item accuracy and completion rate should also be reported. This prevents faster guessing or selective omission from appearing to represent improved learning. Observers can record engagement using a short prespecified coding guide, and a subset of observations should be rated independently to assess agreement. Teachers should record unusual events, interruptions and changes in instructional delivery.

Delayed testing should use parallel material approximately one week after instruction. Comparable testing environments are necessary because a retention score obtained in a hotter room combines prior learning with current assessment conditions. Where comparable environments cannot be achieved, both instruction-period

and test-period exposure should be retained in the analysis. Retention tests should also contain unfamiliar application items so that improvement in repeated practice is distinguished from transfer. Routine classroom marks may supplement these measures but should not replace equivalent assessments.

Adaptation design and lesson allocation

A practical evaluation should separate reversible timetable changes from building changes. After a baseline period, curriculum units can be allocated across early and later lesson slots using a balanced, randomised schedule, stratified by classroom and subject. Each subject and task category should occur in both slots over the evaluation. Teaching duration, content coverage and assessment allowance should be maintained. The first lesson should not always receive the most demanding task. Transport arrangements and school meal times should remain explicit feasibility constraints.

External shade or other durable building changes are better evaluated through a randomised delayed-start design than by assuming that they can be removed each week. Classrooms assigned to an earlier installation can be compared with classrooms scheduled for a later installation during the same calendar periods. A ventilation operating protocol can be evaluated separately where it is feasible to alternate procedures without compromising pupil welfare. If shade

and ventilation are delivered together, the estimated effect is that of the package; attribution to either component requires additional randomised variation.

The evaluation should include sufficient classrooms, baseline observations and post-installation periods to support the intended comparisons. No achieved sample size or statistical power is claimed here. A pilot should estimate classroom-level variation, pupil-level correlation and exposure ranges. Sample-size planning should then use simulation of the proposed allocation and missingness patterns, treating classrooms or schools as the intervention units. Adding many pupil tests to a few classrooms cannot compensate for insufficient independent intervention units.

Exposure summaries and statistical analysis

Two exposure summaries are useful: the time-weighted mean temperature during a defined lesson and cumulative temperature exceedance during preceding occupied periods. The latter weights both the size and duration of an exceedance. Reference temperatures are analytical choices for sensitivity analysis, not validated health limits or Namibian classroom standards. Primary analyses should retain temperature as a continuous variable and examine nonlinearity where the observed range and sample size permit. Separate temperature histories should be created for instruction and assessment.

$$H(\tau) = \sum \max[0, T(k) - \tau] \Delta t(k) \quad (1)$$

In Equation (1), H is cumulative exceedance in degree-hours, $T(k)$ is the indoor temperature during interval k in degrees Celsius, τ is the chosen reference temperature, and $\Delta t(k)$ is the occupied interval duration in hours. The summation includes only intervals within the defined exposure window. Results should be compared across several prespecified reference values to determine whether conclusions depend on one arbitrary choice.

$$Y = \alpha + f(T) + \beta L + \gamma D + \delta(T \times L) + \eta(T \times D) + \theta X + u + v + \varepsilon \quad (2)$$

Equation (2) outlines an observational mixed-effects model. Y represents an equivalent assessment score; $f(T)$ describes the temperature association; L identifies lesson slot; D represents calibrated task difficulty; and X contains prespecified covariates such as baseline attainment, humidity, task form and calendar period. The terms u and v represent pupil and classroom intercepts, and ε is residual variation. The interaction terms assess whether temperature associations differ by slot and task difficulty. This model estimates conditional associations, not an experimentally isolated biological heat effect.

Continuous score models should be checked for residual structure and bounded-score problems. Item-level correctness can instead be modelled with a binomial mixed model, while completion speed requires an appropriate distribution and a prespecified rule for incomplete tasks. Standard errors must respect the unit of randomisation and repeated observations. With few intervention clusters, small-sample corrections or randomisation-based inference are preferable to ordinary pupil-level standard errors. Effect sizes, confidence intervals and model assumptions should accompany any significance tests.

For randomised adaptations, the main estimand should be the total effect of assigned intervention on learning, accounting for allocation strata and calendar period. Post-intervention temperature, window behaviour and comfort are possible mediators and should not be included indiscriminately in that primary model. A separate analysis can examine whether the intervention changed exposure and whether learning patterns are consistent with mediation. Such patterns alone do not identify a causal mediation effect. Intention-to-treat comparisons should be reported alongside delivery and adherence records.

Temperature and clock time may be highly correlated. Model diagnostics should therefore examine whether each lesson slot contains a meaningful range of temperature and whether exposure distributions overlap. No model can recover separate effects reliably when every early lesson is cool and every late lesson is hot. Task-form equivalence, changes in teacher, and temperature-dependent absence also require sensitivity analysis. Missing outcomes should be described by intervention group and weather conditions; imputation should be justified by explicit assumptions and compared with complete-case and plausible adverse-missingness scenarios.

Ethics and data governance

This review analyses published sources and contains no newly collected pupil data. The proposed field evaluation would require institutional ethical review and education-authority permission before recruitment. Participation should be voluntary, assent should be renewed when appropriate, and assessments should not affect grades. Researchers must not deliberately expose pupils to dangerous heat or withhold routine protective measures. A school-approved response procedure should take precedence over data collection when a child becomes unwell or conditions require lessons to stop.

Pupil records should use study identifiers, with the identity key stored separately and access restricted. Public datasets should exclude identifiable child information and school locations where disclosure could create risk. Environmental series, a data dictionary and analysis code may be shared subject to approved governance arrangements. The intervention protocol should document accessibility provisions, handling of withdrawal and procedures for reporting adverse events. Ethics approval, funding and conflict declarations must reflect the eventual investigators and arrangements.

Results and Discussion

Evidence synthesis

The selected empirical studies address three related questions: whether changing classroom conditions alters short-task performance; whether hot school days are associated with accumulated learning; and whether regional classrooms expose children to unfavourable conditions. Table 2 presents these findings without combining their outcome scales. The South African environmental and health studies provide local measurement and welfare evidence, but they do not establish gains from changing lesson schedules. The African working paper extends the geographical evidence base while remaining provisional [9-11].

Table 2: Selected empirical evidence and its limits for rural Namibian application

Study and setting	Design and exposure	Reported finding	Limit for application
Wargocki and Wyon [3]; Denmark	Classroom crossover experiments; manipulated temperature and outdoor air supply	Cooler conditions and greater air supply improved speed on several school tasks; error effects were limited.	Mechanically controlled settings and short tasks do not establish local retention effects.
Porras-Salazar <i>et al.</i> [4]; Costa Rica	Two-week crossover study; 37 pupils; approximately 30 to 25°C cooling	Language and logical-task speed improved; accuracy changes were not significant.	Small study and mechanical cooling; no estimate for low-cost shade in Namibia.
Park <i>et al.</i> [6]; United States	Repeated achievement records; hot school days and school cooling information	Hotter school periods were associated with weaker learning; cooling patterns suggested mitigation.	Outdoor exposure and infrastructure differ from rural Namibian classrooms.
Park <i>et al.</i> [7]; international and United States	Achievement and weather analysis; 58 countries and 12,000 US districts	More hot school days were associated with a lower rate of learning.	Aggregate weather exposure does not identify lesson-level indoor mechanisms.
Van der Walt <i>et al.</i> [9]; South Africa	Repeated temperature and carbon dioxide measurements; 24 classrooms in two schools	Thermal conditions varied by construction; temporary structures had poorer conditions.	Environmental comparison, not a test of learning outcomes; context differs from rural Namibia.
Bidassey-Manilal <i>et al.</i> [10]; South Africa	Cross-sectional study; 904 Grade 4 pupils; weather and reported symptoms	Heat-related risks were examined; the reported temperature-tiredness estimate was not significant.	Symptom and exposure evidence cannot establish a causal attainment effect.
Vidogbena <i>et al.</i> [11]; West and Central Africa	Working paper; georeferenced temperature and primary assessment data in eight countries	High temperatures were associated with lower reading and mathematics outcomes.	Working-paper status and outdoor exposure require cautious interpretation.
Sievertsen <i>et al.</i> [14]; Denmark	School assessment records; test time and breaks across four school years	Later testing was associated with lower performance; breaks were associated with improvement.	Timing and fatigue evidence; classroom heat was not isolated.

Patterns across exposure scales

The synthesis yields a distinction between intervention evidence and exposure evidence. In the classroom experiments, investigators changed aspects of the immediate environment and compared task performance within a limited observation period [3, 4]. In the achievement studies, exposure accumulated over school days and was linked to broader assessment outcomes [6, 7]. The former can inform

the design of lesson-level comparisons, while the latter motivates follow-up beyond a single hot lesson. Neither design establishes how much improvement a specific Namibian school would obtain from adding shade or changing a timetable.

The environmental studies contribute a different result: exposure cannot be represented adequately by a school address or a building label alone [8, 9]. A useful synthesis must retain both the classroom and the occupied period as units of observation. For a future evaluation, a daily maximum would describe an extreme but might occur after pupils leave, whereas a daily mean could conceal a short period of intense exposure during instruction. These interpretations follow from the proposed exposure definitions and should guide reporting alongside the measured learning outcomes. Table 2 therefore summarises complementary evidence rather than eight estimates of the same causal relationship.

Across the experimental and achievement evidence, the defensible conclusion is that thermal conditions deserve attention when evaluating education. The reviewed studies do not supply a single transferable coefficient for rural Namibia. Designs differ in cooling technology, exposure scale, age, climate and outcome. The narrative synthesis therefore supports a locally testable framework rather than a forecast of marks gained from a particular reduction in temperature.

Immediate performance and learning over time

The classroom experiments distinguish task speed from accuracy [3, 4]. This matters because a fixed-duration classroom test can produce a lower score when a pupil works more slowly, even if the proportion of attempted answers that is correct changes little. Such a pattern has practical consequences for assessment, but it should not automatically be interpreted as a loss of retained knowledge. Reporting completion rate, attempted-item accuracy and total-item accuracy makes the distinction visible.

The longitudinal achievement evidence addresses accumulated learning rather than one brief assessment [6, 7]. A proposed Namibian study should consequently link immediate classroom measures to later retention. If an adaptation improves same-day performance but leaves delayed scores unchanged, a claim about lasting learning gains would be premature. Conversely, improved retention under equivalent testing conditions would strengthen the interpretation that pupils learned more during instruction. Temperature at both stages is needed to assess these alternatives.

Memory after instruction deserves separate attention. Cudeiro *et al.* investigated recognition memory following post-learning heat exposure in experimental sauna conditions [15]. The exposure and tasks differ substantially from primary classrooms, so that study supplies no temperature limit or expected school effect. Its relevance here is a hypothesis about timing: conditions between instruction and delayed testing may matter, as well as conditions during the lesson itself. A school study could record subsequent classroom exposure and brief information about intervening conditions without assuming that an adult laboratory result transfers to children. Any explanation involving memory consolidation would require additional evidence.

A transparent interpretation should compare the direction

and uncertainty of immediate and delayed outcomes, rather than selecting whichever result is statistically significant. Table 3 sets out possible patterns for future evaluation. These are analytical possibilities, not findings from Namibian pupils. Their purpose is to make the claims that each outcome can support explicit before an intervention is tested.

Table 3: Potential outcome patterns and their interpretation in a future classroom evaluation

Potential pattern	Interpretation to examine	Evidence still required
Faster completion with unchanged accuracy	A change in work rate may improve fixed-time performance.	Delayed tests and attempted-item accuracy before claiming greater learning.
Higher immediate scores with unchanged delayed scores	The benefit may concern current performance or short-lived acquisition.	Equivalent delayed forms and comparable testing conditions.
Higher delayed scores and transfer	The pattern would support improved retention and application.	Replication, balanced allocation and assessment of missing outcomes.
Lower exposure with uncertain learning effects	The environmental adaptation may work while the educational effect remains unresolved.	Precision, achieved exposure contrast and faithful delivery.
Higher scores among attendees with more absence	The score comparison may exclude pupils most affected.	Attendance denominators and sensitivity analysis for missing assessments.

Lesson timing as an intervention and a source of confounding

Moving demanding lessons to cooler periods is a plausible adaptation, but “early” is not itself a thermal condition. Buildings may retain heat from the previous day, and outdoor conditions may differ substantially across seasons. Pupils may also arrive tired after travel, miss the earliest period or depend on a later school meal. Schools should establish their actual occupied temperature profile before changing a timetable.

The proposed balanced schedule addresses one common error: comparing mathematics taught early with language taught late and attributing the difference to temperature. Each subject, difficulty category and task form should appear across lesson slots. A randomised shift in lesson order estimates the effect of that scheduling policy, which may operate through several pathways. Estimating a separate temperature effect additionally requires exposure variation within slots and careful adjustment. Where that variation is absent, the policy comparison remains interpretable while the independent heat coefficient does not.

Timing adaptations should preserve curriculum minutes. Shortening late lessons may reduce exposure but also reduce learning opportunity. Evaluations should report instructional minutes alongside assessment outcomes, attendance and pupil experience. They should also identify who benefits: an early schedule could improve conditions for attending pupils while disadvantaging those whose transport arrives later. These are empirical implementation questions, not reasons to assume that one timetable is universally preferable.

Timing and cognitive fatigue

The additional timing study reinforces the need to separate temperature from the progression of the school day. Sievertsen *et al.* analysed Danish school testing and reported lower performance later in the day, with an improvement associated with a break ^[14]. Their analysis did not isolate classroom temperature. It therefore demonstrates a competing explanation for late-day scores, rather than proving that moving lessons earlier reduces a heat effect. In a Namibian evaluation, records should include time since the last break, the activities preceding assessment and whether the assigned lesson actually began on schedule.

The interaction between timing and heat should also be interpreted at the policy level. A schedule that performs better may do so because pupils encounter a demanding task before fatigue accumulates, because the classroom is cooler, or through both pathways. That combined benefit can still matter to a school, but the mechanism should remain open unless the design separates it. A balanced allocation should retain regular breaks across comparison groups; changing break duration at the same time as lesson order would otherwise obscure what was tested. Preserving meal and transport access is part of judging whether any observed advantage is usable.

Ventilation and shade require contextual evaluation

The South African measurement studies show why classrooms should be assessed by construction and operating conditions rather than assumed to behave alike ^[8, 9]. External shade can limit incoming solar radiation, while ventilation can improve air exchange. However, opening windows does not guarantee cooling when incoming air is hotter than indoor air. Outdoor dust, noise and security can also constrain window operation. The candidate ventilation protocol should therefore respond to measured conditions and local constraints.

Shade may change glare and daylight as well as heat. These pathways matter for learning, so a building intervention should be evaluated as a complete environmental change. Measurements should record whether pupils can read comfortably and whether airflow is obstructed. Roof insulation or reflective treatments may warrant engineering assessment, but their performance should not be assumed from the present review. Passive options need local installation costs, maintenance plans and occupied-hour exposure measurements before they are compared with timetable changes.

A useful implementation sequence is to document baseline conditions, repair clearly defective windows or shading where appropriate, then test additional measures with a concurrent comparison group. The review does not rank ventilation, shade and scheduling by effectiveness because no comparable Namibian intervention estimates are available. A randomised package comparison can establish whether an affordable combination works; separate component comparisons are needed if schools require a precise allocation between individual measures.

Thermal discomfort and the teaching process

Exposure may influence classroom instruction as well as pupil assessment. The framework allows for a teacher to shorten an explanation, reduce discussion or change the task when a room becomes uncomfortable. These are plausible

pathways to investigate, not established local responses. A short lesson log should distinguish the planned activity from the activity delivered and record time spent on explanation, guided practice and independent work. This would help interpret an apparent pupil effect that coincides with reduced opportunity to learn.

Observation should remain proportionate. Lengthy reporting forms could add work during the very periods being studied and change classroom behaviour. A small number of clearly defined observations, combined with occasional independent checks, offers a more feasible approach. Teachers can also explain why windows were closed, why pupils moved seats or why a planned task was postponed. Such accounts do not replace comparison-group outcomes, but they can identify constraints that a temperature series alone would miss.

Comfort ratings require similar care. An intervention may improve pupils' reported comfort without producing a detectable score change during the observation period. That finding would indicate a welfare-related response and should be reported on its own terms. Conversely, children may become accustomed to discomfort, making a low complaint rate an unreliable assurance of a suitable learning environment. Combining measurements, brief pupil ratings and delivered-instruction records would support a more complete interpretation without treating any one of these measures as a direct estimate of learning.

Task difficulty and educational equity

Task difficulty should be measured within subjects. A mathematics lesson involving familiar multiplication facts differs from one requiring multistep reasoning, just as word recognition differs from inferential reading. A temperature interaction based on a subject label alone could reflect unequal task difficulty, language demands or assessment design. Pilot-calibrated difficulty and a common assessment structure help prevent that error.

The proposed design should prespecify a small number of interaction questions and report their uncertainty. Searching many combinations of subject, grade, gender and attainment after observing results can generate unstable findings. Baseline attainment and accessibility needs can inform planned subgroup analysis, but small groups should not be assigned definitive effects from imprecise estimates. Thermal comfort ratings should be available in language and response formats children understand.

Equity also affects the outcome denominator. An improvement among pupils who attended a hotter day may conceal additional absences among those who could not tolerate the conditions. Attendance and missing assessments should therefore be analysed alongside scores, with follow-up opportunities that do not penalise absent pupils. Likewise, higher-capacity schools may implement maintenance more reliably. Implementation support should be documented so that an apparent intervention failure can be distinguished from incomplete delivery.

Exposure variability and transferability to rural Namibia

Transferring findings requires matching the exposure process, not only the country's broad climate. Two classrooms experiencing the same outdoor temperature can differ in direct solar gain, retained heat, airflow and occupancy. They can also reach their highest occupied

temperature at different times. Baseline measurements should therefore describe the distribution across rooms and lessons, including the duration of elevated conditions, rather than reporting one school-wide average. These summaries would show whether an intervention addresses the periods pupils actually experience.

The unit of transfer is consequently a combination of building, operating practice and school schedule. An adaptation that works in a shaded room with cross-ventilation may perform differently in a room with restricted openings. A scheduling change may be usable in one school and incompatible with transport in another. Schools should document these features when reporting results so that readers can judge whether implementation conditions resemble their own. Replication across contrasting classrooms would support wider decisions more directly than increasing the number of repeated tests in one unusually favourable setting.

Costs and decision relevance

Affordability should be evaluated using local costs rather than assumed from the word "passive". Installation, materials, transport, maintenance, staff training and monitoring all contribute to expenditure. Timetable changes may have low material costs but create coordination or transport costs. A practical cost analysis should specify the evaluation horizon, the payer perspective and how durable investments are annualised.

Schools can compare cost per pupil reached, reduction in occupied heat exposure and changes in delayed learning outcomes. These measures answer different questions. A reduction in exposure is valuable environmental information but does not prove a learning gain. If a learning effect is near zero or uncertain, a cost-per-learning-gain ratio may become unstable and should not be presented as a precise ranking. Uncertainty intervals and scenario analyses are more informative than an unsupported monetary value assigned to each classroom mark.

Regional climate-resilient education planning emphasises the continuity of learning ^[13]. The contribution of this framework is to connect that objective to observable school-level decisions: which rooms are most exposed, when demanding lessons occur, whether an adaptation is delivered, and whether pupils retain more. A simple temperature record becomes more useful when it is linked to teaching and participation, rather than displayed as an isolated environmental statistic.

Interpreting null and inconsistent findings

A non-significant learning estimate can arise because an adaptation produced little exposure change, because the assessment was insensitive, or because the comparison was imprecise. It can also reflect a small educational effect. These possibilities require different responses. Reporting the achieved indoor-temperature contrast, delivery records and confidence interval allows readers to distinguish a failed environmental intervention from uncertainty about the educational response. Statistical non-significance alone should not be described as proof that classroom heat does not matter.

The same reasoning applies to inconsistent subgroup patterns. A beneficial estimate for one task and an uncertain estimate for another do not establish different heat sensitivity unless the interaction itself is supported. Pilot

difficulty, baseline attainment and the number of comparisons should inform interpretation. Primary outcomes and planned contrasts should be specified before data collection, while exploratory patterns should be labelled accordingly. This makes it possible to learn from an initial evaluation without turning unstable estimates into fixed claims about particular subjects or groups of pupils.

Implementation decisions and staged adoption

A school can use a staged decision process while retaining uncertainty about learning effects. The first stage identifies occupied rooms and periods with substantial exposure. The second tests a feasible adaptation against a concurrent comparison and records whether it changes conditions. The third examines learning, participation and cost together. Expansion to additional rooms would be justified by the combined evidence and practical feasibility, with monitoring to determine whether the initial result persists. This process avoids making a district-wide recommendation from one room or one unusually hot week.

Implementation should have clear responsibilities. School leadership can coordinate lesson allocation and maintenance, teachers can document delivery, and researchers can maintain sensors and independent assessment procedures. Pupils and caregivers can identify difficulties related to timing and participation. These proposed roles should be agreed locally rather than inferred from institutional titles. An adaptation that depends on daily operating changes also needs a workable handover when staff change. Evaluation should therefore record whether benefits require continuing specialist support or can be sustained within ordinary school routines.

Limitations and future research

The review is selective, English-language and dependent partly on accessible abstracts and repository summaries. It does not establish the full distribution of findings, publication bias or comparative methodological quality. Its evidence table illustrates complementary designs and should not be interpreted as a systematic review. The proposed field framework has not been implemented, and no local temperature distribution, learning effect, intervention cost or statistically significant Namibian result is reported.

Future studies should first establish measurement reliability and task equivalence, then recruit enough independent classrooms for the planned comparisons. Additional seasons and contrasting regions would help evaluate transferability. Home heat exposure, sleep, journey conditions and teacher responses may explain residual differences but require proportionate measurement. Longer follow-up could examine curriculum progress and retention beyond the initial study period. Combining classroom engineering and education expertise would strengthen interpretation of both environmental change and learning outcomes.

Conclusion

The reviewed evidence supports treating classroom heat as a potentially modifiable constraint on education. Classroom experiments and achievement studies examine different outcomes, so immediate task improvements should be distinguished from lasting learning. For rural Namibia, the specific unresolved question is how measured indoor exposure interacts with lesson allocation, ventilation and task difficulty under locally feasible adaptations.

The proposed framework combines continuous environmental records, balanced lesson schedules, equivalent assessments and delayed retention tests. It separates observational temperature associations from the total effects of randomised adaptations, and includes attendance, instructional time, implementation and cost. These design features would allow schools to assess shade, ventilation procedures and scheduling changes with clearer evidence. The present review does not establish a universal temperature threshold or recommend an untested national timetable change.

The synthesis also identifies the limits of the practical claim. A cooler room, an earlier lesson and a more comfortable pupil are related observations, but they do not by themselves demonstrate improved retained knowledge. The proposed combination of equivalent immediate tests, delayed assessment and transfer items would strengthen that interpretation. Attention to test conditions and missing outcomes is essential because an intervention could otherwise appear successful simply by changing who is assessed or when the assessment occurs.

For school planning, the central implication is to evaluate buildings and pedagogy together. Shade and ventilation procedures should be matched to measured occupied-hour conditions, while lesson changes should be assessed with curriculum time, breaks, meals and transport arrangements intact. The relevant outcome is an improvement that pupils can access consistently and that a school can maintain. Evidence about environmental change, educational response and operational cost should therefore be presented alongside each other.

The next research step is a pilot that establishes reliable measurements and equivalent tasks, followed by a sufficiently replicated comparison across classrooms and periods. Confirmation of learning benefits would support broader testing in contrasting Namibian settings. If benefits remain uncertain, reporting achieved exposure differences and implementation experience would still clarify how subsequent studies should be designed. This review provides that evaluation structure; local effect estimates and comparative adaptation rankings remain questions for prospective research.

Recommendations

School-level pilots should begin with occupied-hour temperature and humidity monitoring linked to existing lesson schedules. Education authorities and researchers should jointly develop equivalent assessments, safe operating procedures and feasible allocation plans before testing adaptations. Shade and ventilation measures should be evaluated with local engineering advice, while scheduling trials should preserve teaching time and account for travel and school meals. Future reporting should include delayed learning, attendance, delivery and actual costs so that environmental improvement can be connected to educational benefit.

Data Availability

This article synthesises publicly accessible publications identified in the reference list. No new classroom or pupil dataset was generated or analysed. Fig 1 is an original conceptual framework, and Table 1 specifies a proposed measurement plan. The field evaluation and analytical models remain proposals for prospective implementation.

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