Inception Report

Improving Learning Through Classroom Experience in East Africa: Temperature, Lighting, and Sound Quality

Björn Haßler[1], Xuzel Villavicencio Peralta[1] , Grace Macharia[1], Oluyemi Toyinbo[1,3], Mauricia Nambatya[4], Joel Mtebe[2], Jens Schaffer[1,5], Pawel Wargocki[6], Taskeen Adam[1]

1st March 2023

https://doi.org/10.53832/opendeved.0286

[1] Open Development and Education Ltd (OpenDevEd, UK and Sierra Leone)

[2] University of Dar es Salaam (UDSM, Tanzania)

[3] Oulun yliopisto (University of Oulu, Finland), Teknillinen tiedekunta (Faculty of Technology), Rakennus-ja yhdyskuntatekniikka (Civil Engineering)

[4] Haileybury Youth Trust (Uganda)

[5] YesCon (Germany)

[6] Indoor Environment, Department of Environmental and Resource Engineering, Danmarks Tekniske Universitet (Technical University of Denmark)

About this document

Recommended citation:

> Haßler, B., Villavicencio Peralta, X. A., Macharia, G., Toyinbo, O., Nambatya, M., Mtebe, J., Schaffer, J., Wargocki, P., & Adam, T. (2022). *Improving Learning Through Classroom Experience in East Africa: Temperature, Lighting, and Sound Quality – Inception report* (Improving Learning Through Classroom Experience in East Africa No. 1). Open Development & Education. https://doi.org/10.53832/opendeved.0286. Available from https://docs.opendeved.net/lib/44YQ4VEG. Available under Creative Commons Attribution 4.0.

Contents

Figures

1. Introduction

'Improving Learning Through Classroom Experience in East Africa' is an FCDO-funded programme focusing on investigating whether modification of the built environment (temperature, light intensity and acoustics) can positively impact on the classroom experience to improve learning. The research is not expected to establish causation to learning, but instead to act as a proof of concept to build awareness and understanding of the said issue and to spur on further research.

Classrooms in Sub-Saharan Africa can often be uncomfortable places to be, let alone to teach and learn in. Sweltering **temperatures** have proven negative physiological impacts – regardless of children's level of acclimatisation. A meta-analysis estimated that learning improvement can be increased by 20% with a temperature reduction of 10℃ (↑Wargocki et al., 2019). Learning is being impeded across the region by excessive temperatures. One study, looking at temperature in just eight schools for five days in South Africa, recorded an indoor temperature of up to 53.8℃ (↑Bidassey-Manilal et al., 2016).

Poorly lit, or overly sun-exposed, classrooms make it much more difficult to read, and introduce health risks (↑Ibhadode et al., 2019). Lack of, or excess **light** excludes children with poor eyesight, introducing a layer of inequity. An experimental study in Nigeria assessed 180 classrooms and found that only 14% of students had adequate lighting at their desks, and virtually no classrooms had suitable light illuminating the board (↑Ibhadode et al., 2019).

During the rainy season, it becomes nearly impossible to teach, given the **sound** of rain on corrugated iron. Overall, these classroom conditions, all infrastructural in nature, are fundamentally part of the learner experience.

Examples of small changes in building design, or retrospective adjustments, have anecdotally been shown to improve learning experience in the region. There is little research on improving learning experience through infrastructural development – or how to achieve these changes in sustainable and cost-effective ways. There is significant evidence that providing more classrooms as an input is not effective (in the absence of accompanying resources such as teachers and educational materials), but little research on the effect of improving learning experience within a classroom. This research is intended to test a 'proof of concept', that is, to explore the potential of low cost, carbon smart adjustments to the educational built environment on learning and inclusion, particularly in the face of climate change and other shocks such as the COVID-19 pandemic. The findings will raise awareness and understanding of this neglected area and likely promote more rigorous study and action. Such work can lay the foundation for changes that could improve the efficacy of large infrastructural investments across the region.

The recent IPCC report highlighted that the impact of human-induced climate change is being manifested in climate extremes across the globe, which include heatwaves, heavy rainfall, droughts, and tropical cyclones (↑Lahn, 2020, p. 10). It warns global warming between 1.5 and 2 degrees Celsius will be exceeded during the 21st Century, unless considerable reductions in carbon dioxide and other greenhouse gas emissions occur in the next few decades (↑Lahn, 2020, p. 17). This therefore places considerable importance on infrastructure that is resilient to the effects of extreme weather and warming temperatures. This research will focus on interventions that can help address learning, rather than solely focusing on Disaster Risk Reduction, and should be seen as part of a holistic systemic adaptation to the consequences of climate change.

1.1. Aims

The overarching aim of this proposed research is to investigate whether modification of the built environment (temperature, light intensity, and acoustics) can positively impact on the classroom experience to improve learning. The research is not expected to establish causation to learning, but instead to act as a proof of concept to build awareness and understanding of this issue and to spur on further research.

The confirmed aspects of classroom experience to be investigated are:

- Temperature
- Lighting
- Sound and acoustics.

Oxygen/Carbon Dioxide concentrations might be included in the research as additional features of the educational experience. The research may likely propose and trial interventions to improve classroom experience, such as changing the layout of the classroom, the impact of tree cover and green spaces around the classroom, temperature reduction or improved ventilation. However, we will endeavour to justify these additions within the context of this work. Our approach will integrate a systemic view of education and move beyond a conversation around infrastructure as an input.

1.2. Objectives of work

The objective of the work is to garner greater insight into the role of infrastructure in students' and teachers' experience. The research proposes to move past anecdotal case studies and provide evidence through primary data measurement. The research team will work in partnership with organisations with first-hand experience of building school infrastructure – and a practical understanding of the challenges involved.

The three specific areas that provide an outline for the investigation are:

- temperature,
- lighting,
- and sound.

These variables will explore the impact of seasonal changes. The research will deliver data through mixed methods, through both quantitative measurements and qualitative research to understand different stakeholders' experiences; we produce reliable findings contributing to the evidence base with view to proposing options for concrete action as well as guiding further research. The research design will include physical experimental elements in addition to qualitative insights, including participatory research with key stakeholders. Furthermore, the research will review the cost of any proposed interventions (using the Building Evidence in Education Cost Guidance and Standards) and calculate estimated or cost-effectiveness of interventions.

2. Literature review

There is a broad range of factors affecting a child's learning experience. While considerations such as pedagogy and nutrition have been widely investigated, others have not. This work fills an important gap: the question of the built environment (↑Barreda & Assmann, 2021; ↑Lan et al., 2020; ↑Porras-Salazar et al., 2018; ↑Tran et al., 2022;↑Wargocki et al., 2020).

Indoor Environmental Quality (IEQ) collectively denotes the conditions that are part of a building and their effects on the building's occupants. Temperature, lighting, and acoustics are conditions that are part of the group of physical factors; however, there are also biological factors (bacteria, virus), outdoor factors (combustion emissions), and chemical factors (CO_2, O_3, etc.). ↑Cartieaux et al. (2011) state that a combination of these factors can impact the classroom's Indoor Environmental Quality. ↑Toyinbo (2017) mentions several studies that show some effects of Indoor Environmental Quality on students and staff, which can be grouped in healthy problems, reduction in productivity, comfort, and academic performance.

The question of a conducive physical learning environment is a global concern. For example, in the USA, the publication ↑Effects of Classroom Ventilation Rate and Temperature on Students' Test Scores (Haverinen-Shaughnessy & Shaughnessy, 2015) demonstrates the relation that adequate temperature and ventilation in a classroom have on improving students' test scores. This study shows the potential learning outcomes that could be achieved when indoor environmental factors are taken into consideration.

Moving to the European region, in countries such as Spain and Portugal, the study ↑Influence of Air Temperature on School Teachers' Mood and the Perception of Students' (Behavior Boix-Vilella et al., 2021) explores how the difference between outdoor and indoor temperature, indoor humidity, and indoor temperature seem to have an impact on teachers' mental fatigue and students' behaviour.

In the Asian country, China, the publication ↑Cognitive performance was reduced by higher air temperature even when thermal comfort was maintained over the 24–28 °C range (Lan et al., 2022) has demonstrated that even when a classroom has acquired a value within the range of thermal comfort, a cooler temperature has a better impact on the cognitive performance of the students. This study also highlights the benefits of ventilation in reaching thermal and cognitive performance in a warm environment

The problem has also been studied in sub-Saharan Africa. The paper ↑Classroom Temperature and Learner Absenteeism in Public Primary Schools in the Eastern Cape, South Africa (Pule et al., 2021) notes links between absenteeism and indoor schooling temperatures, suggesting that the lower the temperature, the higher the students' absenteeism. Even though absenteeism can be attributed to many factors, the study considers reaching a thermal comfort level fundamental for the planning and design of a school.

Regarding temperature, research indicates that cognitive functioning decreases when the environment is not within the ‘zone of thermal comfort’. In particular, the rate of performance is often lower at higher temperatures than at lower temperatures (↑Blaker & Andrew, 2020). There are different cross-cutting themes and areas of analysis within GESI (Gender Equity and Social Inclusion) — e.g. research around temperature and gender (↑Ahmed et al., 2022). Women, for example, have higher thermal comfort temperatures. Furthermore, certain disabilities can be exacerbated by high temperatures, and lastly, different cultures, ethnicities, and groups of people, are likely to have different ‘zones of thermal comfort’.

Importantly, everyone has their own ‘optimal temperature zone’, which differs depending on what you are used to / how long you have spent in certain conditions/age. However, the cooler end of the temperature zone is always better than the warmer for cognition. The issue of classroom conditions does not only affect students, but also teachers. As a result, we must also consider the impact on teachers. Finally, we note that the focus on temperature is particularly significant for Africa due to the likelihood of rising temperatures due to global warming, with projected intense heat extremes and overall temperature increases (↑Kapwata et al., 2018).

3. Approach and team configuration

The research described in this inception report is part of a broader research programme, which is undertaken by two separate teams.

3.1. Team 1. At-scale learning assessment

Team 1 will focus on at-scale learning assessment. The team will focus on assessment of the overall environment conditions and investigate how these can be linked to learning outcomes.

Team 1 is composed of researchers from Fab Inc. and Laterite.

Fab Inc. is a boutique social enterprise providing consulting and advisory work to a range of education/international development clients. They are International Education Specialists with substantial experience working in both high and low- and middle-income countries across the education policy cycle. They recently produced a self-funded ↑Guidance Note on Climate-Smart School Construction Planning to stimulate a discussion on what has been an under-considered issue. This note looked at how the materials and methods used for school construction and ongoing operation can affect both the emissions and climate burden of the school, but the temperature, light, and sound within classrooms can also impact learning.

Laterite is a data, research and advisory firm dedicated to bringing high-quality research services to the most underserved markets. With ten years of experience in data collection and development research in East Africa, we strive to carry out impactful research that helps decision-makers find solutions to complex development problems. Our approach is structured, data intensive and embedded in the local context. Laterite works exclusively with organisations active in social impact efforts and development research in East Africa, in core sectors of education, public health, agriculture, youth and livelihoods, and urbanisation and migration, with gender and social protection as cross-cutting themes.

3.2. Team 2. Improving Indoor Environmental Quality

Team 2, represented in this report, will focus on practical approaches to improve Indoor Environmental Quality (IEQ). This includes exploring options to retro-fit schools, making changes to buildings and the school environment. Team 2 comprises researchers from the following organisations:

- Open Development & Education Ltd (OpenDevEd, UK and Sierra Leone);
- University of Dar es Salaam (UDSM, Tanzania);

- Oulun yliopisto (University of Oulu, Finland), Teknillinen tiedekunta (Faculty of Technology), Rakennus- ja yhdyskuntatekniikka (Civil Engineering);
- Haileybury Youth Trust (Uganda);
- Yescon GmbH (Germany);
- Indoor Environment, Department of Environmental and Resource Engineering, Danmarks Tekniske Universitet (Technical University of Denmark).

3.3. Harmonised scope of work

Team 1 focuses on the collection and analysis of primary and secondary data to better frame and evidence the relationship between climate and learning/cognitive functioning. OpenDevEd will focus its work on the identification and testing of practical changes to the physical environment and infrastructure of schools.

Both teams will look to complement their respective work in order to ensure efficient use of time and resources, working to harmonised scopes of work, including work plans.

4. Methodology

The evaluation will take place in two phases (Discovery, Alpha), which might be followed by two as yet unfunded phases (Beta, Live). Overall, we will utilise a mixed-methods approach, that includes scoping, situational analysis, systematic review of existing literature and data, stakeholder interviews, and focus groups.

From an **engineering perspective**, aims to

- determine what the most conducive and optimal learning environments are likely to be in Tanzanian schooling contexts (rural vs urban; coast vs central plateau);
- consider the approaches (structural/engineering aspects) already being used to create schools (types of materials, devices, strategies);
- consider innovative approaches that could be introduced (including modelling).

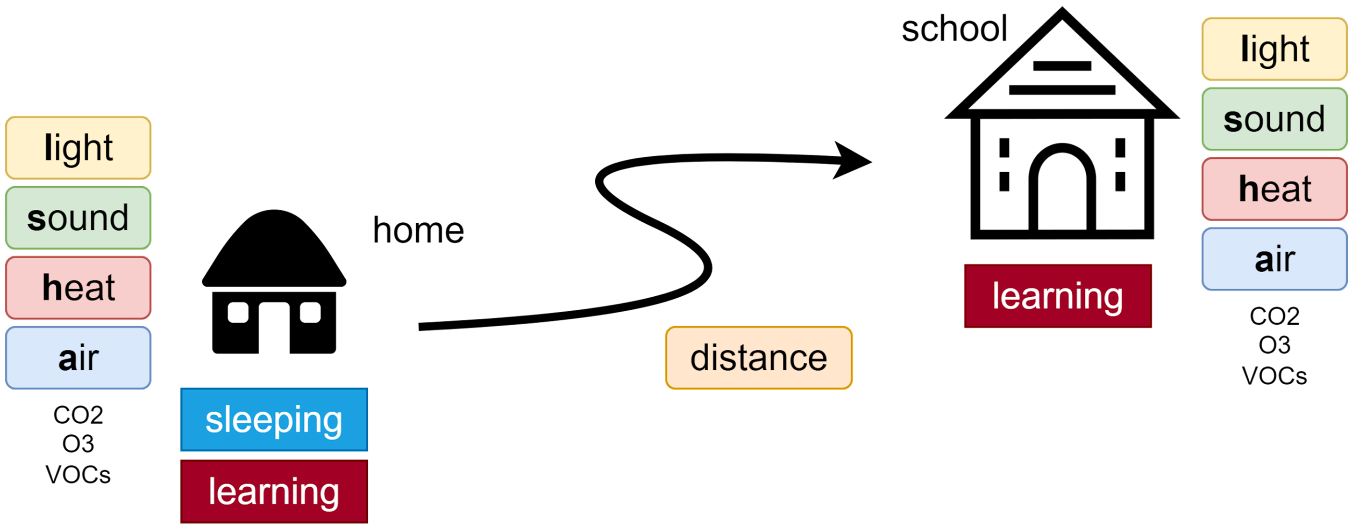
To make such engineering approaches work in practice, we need to capture the **education systems perspective**, including:

- perspectives and knowledge/awareness of stakeholders (government, construction firms, donors, teachers, parents, children),
- formal regulations affecting the above stakeholders (national/regional government policies, donor policies).

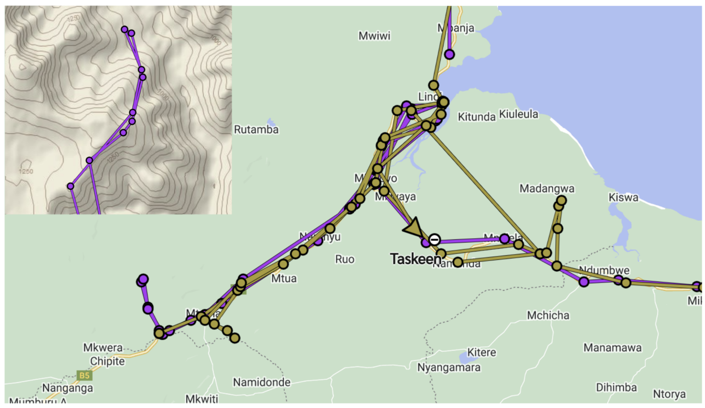
Given the focus of this work on Indoor Environmental Quality, such perspectives are collected informally, rather than through formal qualitative research processes.

While we focus on the classroom experience regarding temperature, lighting, and sound quality, we likely need to go beyond the context of 'classroom' and the three factors. Children do not only learn in school, but may also learn at home or community centres. The following diagram shows the three factors plus ventilation ('air'), both within the school/classroom environment and at home. In this scenario adequate sleep is important for children to be prepared for school.

Figure 4.1. Factors to be measured in learning environments



Therefore, we feel that the focus on the environmental conditions needs to be considered holistically, considering both the school and home and the factors of light, air, sound, and heat, as well as the distance between the school and home. All of these are construction-related factors that ultimately influence a child's wellbeing and readiness to learn.



Our work is 'location-aware', both in terms of local geography and location within the national context. The image shows GPS tracks collected during recent EdTech Hub research for the EdTech Hub, illustrating elevation and the 'last mile' journey to a school, offering clues about catchment area planning, and microclimate considerations, such as prevailing winds).

4.1. Phase 1 — Discovery

In Discovery, we seek to learn from experts and organisations which focus on innovative school buildings inTanzania and other countries across Africa.

Currently, conversations were held with some of the following:

- Lyra in Africa: NGO that provides hostels for secondary girls. These facilities are relatively near to the secondary schools and located in hot, cold areas and tropical areas of Tanzania
- Core-Tanzania: NGO focused on providing quality education for rural children in Tanzania. School building has 4 classrooms built and 1 under construction.

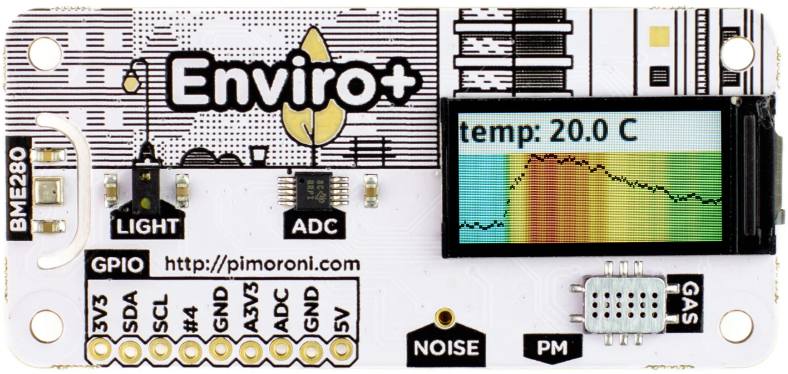
- Catriona Forbes: architect with experience in building Carbon-smart schools in Sierra Leone
- Haileybury Youth Trust Uganda: a charity that trains young people in climate-friendly construction and builds schools, homes and water tanks
- Localworks: group of architects specialising in the design and implementation of ecological architecture in East Africa, mostly in the educational, hospitality and public sectors.
- Sovereign House: A charity, whose main project is the building of a blue printed school in Ghana.
- 14 trees: Company focused on building 3D printed houses and schools

Lyra in Africa and Core Tanzania have shown interest in this study and are open to provide their accommodation and school facilities for the installation of sensors and trialling of retrofits. Both organisations are currently building facilities which could be an opportunity to implement the recommendations as result of the study.

4.1.1. Sensors

We seek to explore adequate measurement approaches to current conditions (temperature, lighting, acoustics) in schools across Tanzania by installing the sensor kits in schools and students' homes.

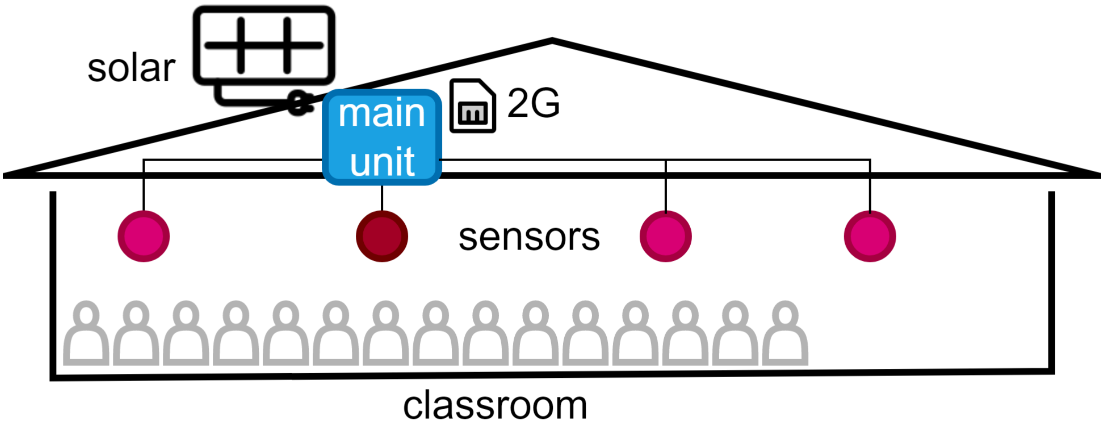
This includes thorough desk-based research, determining how international insights can be applied to the Tanzania context. We build on our initial background research to develop a set of initial approaches ('Guidance Iteration 1'). Initial approaches will be validated through computer modelling. For modelling, e.g., of temperature, we consider approaches to natural ventilation (ventilation rate / wind and stack pressure effects). We will utilise and compare simpler/free tools (such as OptiVent) with more expensive tools (e.g., DesignBuilder). Similar modelling techniques will be applied to the other factors.



For primary measurements, we will utilise and validate affordable sensor-arrays with higher-precision devices. For example, we draw on the combined Enviro+ sensor, available for Raspberry Pi and Adafruit Feather/Wing. In school-based experimentation, teachers, students, and parents are not just bystanders, but are actively engaged in the processes, enabling an appreciation of the effect of the environmental conditions.

In detail, we use the Raspberry Pi (↑Zero, ↑Pico) and ↑Feather with ready-build boards (HAT/Wing) featuring a range of sensors for light, air, sound, and heat (e.g., ↑BME280 temperature, pressure, humidity sensor, ↑MEMS microphone, ↑MICS6814 analog gas sensor, ↑LTR-559 light and proximity sensor, ↑LTR390-UV-1, ↑PMS5003 Particulate Matter Sensor, ↑SGP40 Indoor Air Quality). Each unit will drive several sensors in several locations within the classroom; air quality and noise will only be measured in a central location, while light and temperature will be measured in different locations. We will test these sensors against professional instrumentation to determine accuracy.

Figure 4.2. Sensor arrangement in a classroom

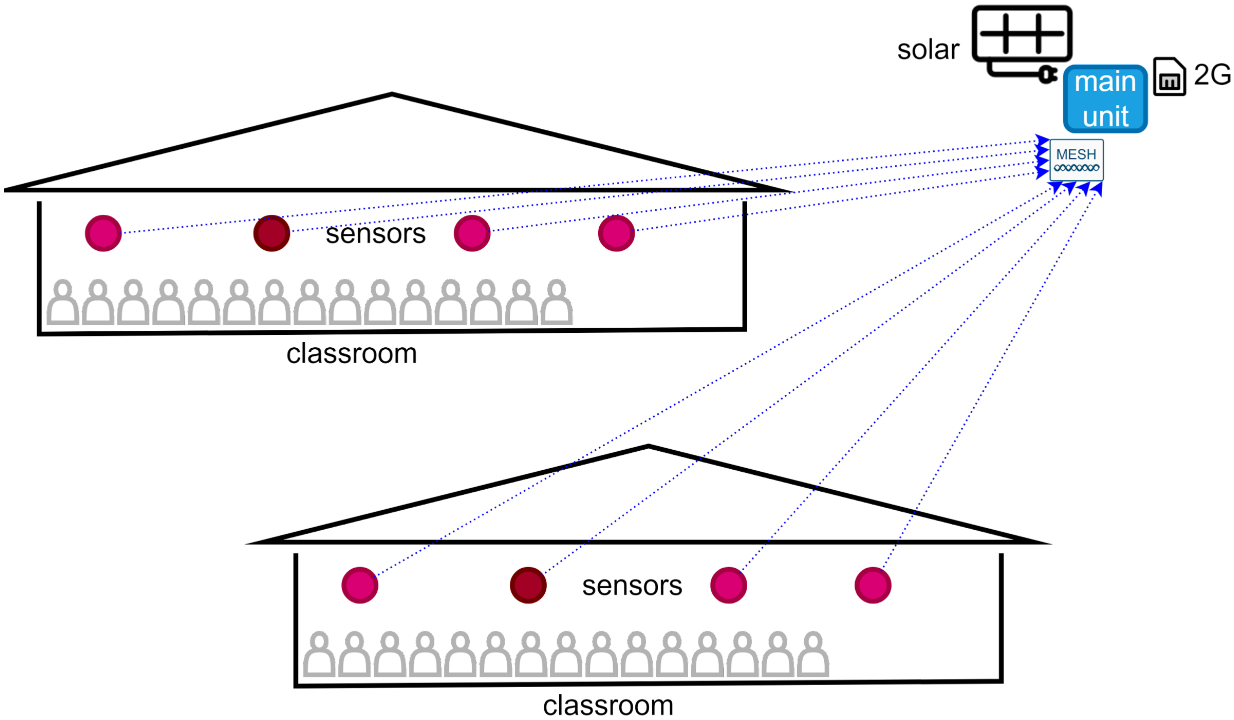


Sensors need to be readable remotely. To save cost, we will explore 2G connectivity (e.g., ↑SIM800C GSM/GPRS), which should be sufficient; however, we will also compare this with options for 4G connectivity (e.g., ↑SIM7600G-H 4G). Units will be fairly low power and operate continuously (LiPo / solar recharge). In this way, we will establish real-time data feeds from our sites.

Environmental monitoring of schools will need to be undertaken at larger scales, both in Tanzania and across Africa. Therefore, we will explore options for local hardware assembly from components, as well as manufacture of integrated devices. Propositions for such approaches will be included in our recommendations.

In comparison with Figure 4.2. Sensor arrangement in a classroom, the following figure shows a whole-school arrangement, utilising Matter / ZigBee sensors.

Figure 4.3. Sensor arrangement across a school, using low-cost Matter / ZigBee sensors



The overall rationale for considering Matter / ZigBee sensors is that they are used in home automation systems, which means that devices are mass-produced and, therefore, available cheaply. Matter is a new standard for home automation, which also allows for mesh networking. It is supported by the Connectivity Standards Alliance (formerly the ZigBee alliance). ZigBee is a particular standard which utilises radio frequency for transmitting home automation signals. Unlike WiFi-based home automation systems, radio frequency-based systems have much lower power consumption. ZigBee devices are readily available, and include a range of sensors for temperature, humidity, and light, as well as – less commonly – sensors for other aspects of air quality. While these sensors are not as accurate as industrial sensors, they are cheap (around $10 per sensor) and they have very long-lasting battery life (typically 2 years or more).

As shown in Figure 4.3. above, a ZigBee-based system would consist of several sensors per classroom, which are battery powered. The sensors would need to be secured; however, on the whole, they are very unobtrusive and inconspicuous. The sensors transmit to a ZigBee hub, either directly or via a mesh network. Due to the long range of radio frequency (and low building complexity in schools), only one ZigBee hub is needed per school. The ZigBee hub is implemented using a Raspberry Pi with a ZigBee dongle; the Raspberry Pi (as with Figure 4.2.) is solar-powered and connected to 2G, transmitting sensor data via the internet.

4.1.2. Sensor trialling

We will install the units together with a local technician, to be able to revisit installation sites in case of failure. Ideally, units will be left in place permanently and need to be adequately secured. However, depending on the local circumstances, it may be necessary to have portable units. All units will collect reference data across this set of schools. Our aim is that sensors collect data from different seasons.

We note that, outside trials, no actual audio data will be transmitted: All processing takes place locally in real time, automatically anonymising data. Nevertheless, this will be examined very closely from an ethics and GDPR perspective.

In this phase, we hold co-design workshops with school builders, government NGOs, civil engineers to conduct participatory research. Also, we undertake community engagement (interviews and workshops with parents, teachers, district officers). Importantly, we will also apply a cultural lens. There are indigenous ways of building cooler rooms, which may conflict with the aspiration to have 'Western' cement-type classrooms that are less favourable for learning (cf., ↑Burkina Faso: Why some West African architects are choosing mud over concrete; National Geographic, 2021).

The selection of schools will depend on different factors, such as local conditions, accessibility, type of connectivity, permits required to install sensors, and the feasibility of implementing retrofits, among others.

To ensure that our research is not isolated, we will first consider working with Shule Bora programme schools, in the regions agreed with Fab Inc. and Laterite:

- Pwani,
- Mara and
- Dodoma.

However, it is imperative that we form as many innovative initiatives and organisations as possible; therefore, we will also consider working in other regions.

4.2. Possible approaches

We will now give a broad overview of potential approaches. These are based on our analysis of the literature as well as the experience of the team. However, while this is based on African insights, these are not based specifically on Tanzanian insights.

Classrooms typically have roofs made from sheet metal. Studies in temperate zones show that ventilation has an inverse relationship with temperature. However, in hot climates, radiation from the underside of the roof into the classroom appears to be the dominant control of temperature to such an extent that improvements in ventilation make little difference. While this needs to be further investigated, a potential priority may be to reduce heat radiation rather than to improve ventilation.

Figure 4.4. A Tanzanian classroom, showing the structure of the rafters and roof

A critical factor in reducing temperature is shade. One possible approach includes strategic changes to the outdoor spaces surrounding classrooms, such as (trans-)planting appropriately selected trees that can rapidly grow and provide shade to the classrooms. Trees also act as windbreaks. Overall, trees offer a natural and sustainable way of controlling the high temperature in classrooms. Further, trees can form part of existing school gardens — a common feature in Tanzanian schools — further increasing pedagogical and socio-emotional benefits of school gardens to provide valuable and enjoyable learning space. In planting trees, we do need to consider the effects of tree roots on buildings, to ensure that buildings are not compromised.

Heat radiation can also be affected through coats of paint on the metal roof. Practical experience seems to indicate that leaving the metal roof bare may be the best option, as it reflects heat. However, in some settings coloured roofs are desirable, and the metal roofs are painted, absorbing heat, which is then re-radiated into the classroom (EMI Tech, 2019). This aspect of buildings requires further investigation.

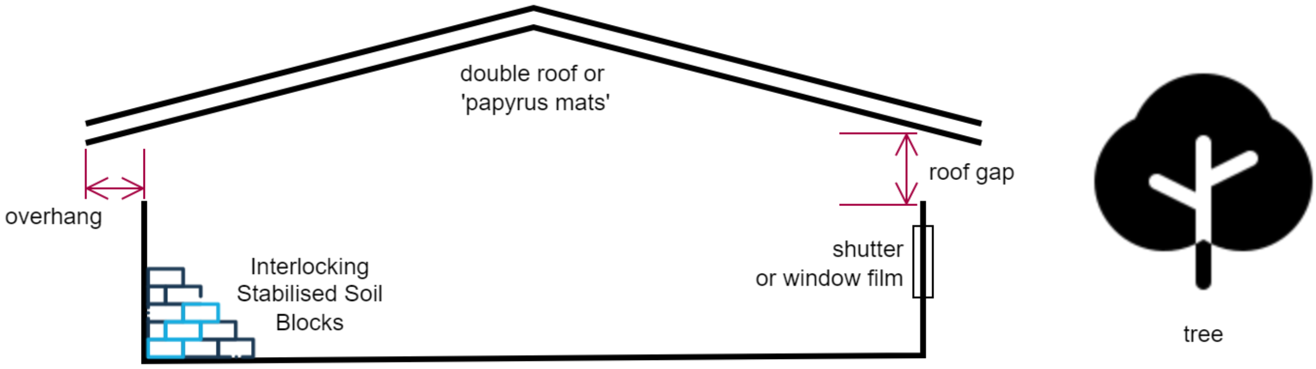
Many classrooms in Tanzania have a triangular roof supported by rafters. Typically, there is a gap between the roof and the walls (see image below). It may well be possible to affect temperatures by increasing the space between the roof and the walls. To stop birds and bats from entering the classroom, a wire mesh could be used to block access. Another option to create a cooler environment outside the classroom is to increase the overhang of the roof.

Less often, a horizontal ceiling is inserted, ostensibly to insulate the hot roof from the classroom. However, unless the roof space is well ventilated, this may actually be counterproductive. Instead, it may be better to construct an insulated by adding an equivalent structure to the ‘papyrus mats’ used in Uganda (↑Tangjuank & Kumfu, 2011). These mats do not only insulate the roof, but also improve the acoustic quality of the classroom, particularly reducing the noise due to rain. It may also be advantageous to construct double roofs (akin to ‘double glazing), where a second roofing sheet with a thin aluminium radiant barrier is added for reducing the temperature of the classroom environment. However, this may not be economically feasible.

Some of the above options are possible for retrofitting schools, others are only feasible for new schools. Where new classrooms or schools are built, the use of Interlocking Stabilised Soil Blocks (ISSBs, also known as Interlocking Compressed Earth Blocks, ICEBs). Made mainly with subsoils mixed with little cement, and sand, they are compressed (using specialised machinery). Interior gaps offer cooler temperature. This environmentally sustainable building material is used widely in Uganda and also appears to be in use in Tanzania.

Lighting in the classroom can be controlled using shutters on windows and positioning doors and windows better in relation to the blackboard. We also note that a classroom layout in rows is not pedagogically conducive, as it reinforces 'talk and chalk'; moreover, alternative classroom layouts may also be conducive to children's physical wellbeing, for example allowing more movement.

Figure 4.5. Factors influencing the classroom environment



It is needless to say that these insights are preliminary. Costs need to be determined, and possible designs need to be field tested. At the end of Discovery, we will have a much better understanding of what approaches are actually feasible in Tanzania. These approaches will be trialled in Phase 3.

4.2.1. Comfort surveys

We note that it is important to not just focus on 'absolute values' of environmental properties, but also to understand subjective perceptions. A comfort survey will be done to evaluate how comfortable the students are in their classroom environment. The survey will be translated into Tanzania's native language, Swahili.

The first set of questions to be asked will involve how the students perceive their classroom/school environment in terms of temperature, humidity and air freshness. Some of the questions that would be asked are included below. The boxes show preliminary translations that will be validated beforehand with teachers and students.

Figure 4.6. Example of survey questions translated into Swahili

1) How do you feel in your classroom environment? ***Unajisikiaje katika mazingira ya darasa lako?***

a) very cold – *baridi sana*

b) cold – *baridi*

c) neither cold nor warm – *si baridi wala joto*

d) a little warm/hot – *joto kidogo/moto*

e) warm/hot – *joto/moto*

f) very warm/hot. – *joto sana/moto*

2) How fresh is your classroom air condition? ***Hali ya hewa ya darasa lako ni safi kadiri gani?***

a) very fresh – *safi sana*

b) fresh – *safi*

c) neither fresh nor unfresh – *si safi wala chafu*

d) a little unfresh – *chafu kidogo*

e) unfresh – *chafu*

f) very unfresh – *chafu sana*

3) How humid is your classroom? ***Darasa lako lina unyevu kiasi gani?***

a) very humid – *unyevu mwingi*

b) humid – *unyevunyevu*

c) a little humid – *unyevu kiasi*

d) not humid nor dry – *sio unyevu wala kavu*

e) a little dry – *kavu kidogo*

f) dry – *kavu*

g) very dry – *kavu sana*

Another set of questions would involve asking about student's comfort in their classroom environment. The following box has an example.

Figure 4.7. Example of survey questions about students' comfort

1) When do you feel most comfortable in your classroom/school environment? *Ni wakati gani unajisikia vizuri zaidi katika mazingira yako ya darasani/shuleni?*

a) Morning – *asubuhi*

b) Noon/breaktime – *mchana*

c) Afternoon – *alasiri*

2) How comfortable is your classroom temperature and air freshness? *Je, halijoto ya darasa lako na hali ya hewa safi ikoje?*

a) Very comfortable – *vizuri sana*

b) Just comfortable – *starehe tu*

c) I am fine with it – *Niko sawa nayo*

d) Just uncomfortable – *usumbufu tu*

e) Very uncomfortable – *wasiwasi sana*

3) How comfortable is your school's uniform? *Je, sare ya shule yako ikoje?*

a) Making you hot – *kukufanya kuwa moto*

b) Just fine – *sawa tu*

c) Making you cool – *kukufanya baridi*

It is also important to ask the student about what they would like to change concerning comfort in their classroom environment. The following box has an example.

Figure 4.8. Example of survey questions on aspects that should change on classroom environment

1) How would you like your classroom temperature to be? *Je, ungependa halijoto ya darasa lako iweje?*

a) Warmer – *joto zaidi*

b) Just as it is – *kama ilivyo*

c) Cooler – *baridi zaidi*

2) How would you like your classroom air to be? *Je, ungependa hewa ya darasa lako iweje?*

a) More air/fresher – *safi zaidi*

b) Just as it is – *vile ilivyo*

c) Reduced air – *hewa iliyopunguzwa*

3) When do you want the change in 1 and 2 above? *Je, unataka mabadiliko ya 1 na 2 hapo juu lini?*

a) Morning – *asubuhi*

b) Noon/breaktime – *mchana*

c) Afternoon – *alasiri*

In addition to the above, school headteachers/maintenance personnel/classroom teachers would be asked about the condition of the schools/classrooms in terms of their comfort and that of their students. These subjective measurements from questionnaires will be evaluated with objective data collected with sensors/data loggers.

The questionnaires will also be adjusted and extended to students' homes, with the purpose of comparing how their comfort varies from one learning environment (school) to another (home).

The lead investigator will fill a field checklist concerning the building characteristics before and after intervention to keep track of the important changes in the building structure. Some of the topics in the checklist are shown in the checklist below.

Figure 4.9. Checklist for buildings

1. Roof type
2. Roof membrane
3. Main frame structure material
4. Type of foundation
5. presence of basement
6. Renovation periods
7. Air quality complaints
8. Number of occupants in the school/classroom
9. Ceiling type
10. Ventilation type/HVAC
11. Wall finishing/painting
12. Potential source of pollutants near the school area
13. Plumbing system condition
14. Classroom dimension/size/area
15. Lighting being used
16. Types and number of windows
17. Odour perception in the school/classroom area.

4.3. Phase 2: Alpha — experimentation

In this phase, we undertake experiments to measure and test different approaches that make environments more conducive to learning. We combine our insights from Discovery with the reality of constructing and improving classrooms. Our key question remains how we can create more conducive environments for learning that are cost-effective, considering scalability and VfM. However, moving into this practical phase, we can begin qualitatively to assess what impact we have on teachers and students to teach and learn effectively.

Phase 2 will have given us insights into how many schools we can feasibly conduct practical experiments. We hope that experimentation will be possible in a fair number of schools, depending on the relations that we have been able to build with local NGOs. Together with implementing partners, we explore retro-fitting, as well as new prototypes for classroom design.

Retrofitting and new builds raise both engineering challenges, and socio-economic challenges. Both types of challenges are explored, including both measurement of the physical environment and social science approaches (interviews, focus groups; practical activities including taken-based voting, etc). Importantly, each intervention will be determined in conjunction with community consultation. In other words, our cycles of "suggest and test" are driven by the research team acting together with the local community. We will explore the following trial intervention, focusing on testing hypotheses such as:

- Covering corrugated roofs with papyrus mats, reduces noisiness during rainy seasons as measured by measure X and reduces heat measured by measure Y; this is sufficient to allow teaching and learning to continue (in all or certain pedagogical approaches).
- Adding 1 metre of overhang to a classroom building adds shade outside the classrooms, and reduces the light and heat coming into the classroom, enabling better illumination and temperature conditions, as measured by measures Y and Z.
- Applying reflective, heat-reducing window film, this will reduce the light and heat, enabling better illumination and temperature conditions, as measured by measures Y and Z.

The end of the alpha concludes the funded period.

4.4. Phase 3: Beta

The funded period is relatively short, and does not allow longer term assessment of the impact of improved physical classroom environments on learning. We feel that sustainability and sustained outcomes will not just be influenced by shorter term programmes delivering written outputs; rather, longer-term approaches are needed.

One of our strategies is to include a research assistant and/or PhD and/or Masters students as a key member of the team, based at the University of Dar es Salaam. To enable this longer-term work beyond the scope of the funded programme, OpenDevEd will collaborate with the student beyond the duration of the programme; this includes, for example, providing research expenses in future years, offering continued integration with the OpenDevEd team, and engagement from OpenDevEd in writing further outputs.

Another strategy will be to seek further funding, to enable a broader beta phase, followed by 'live'.

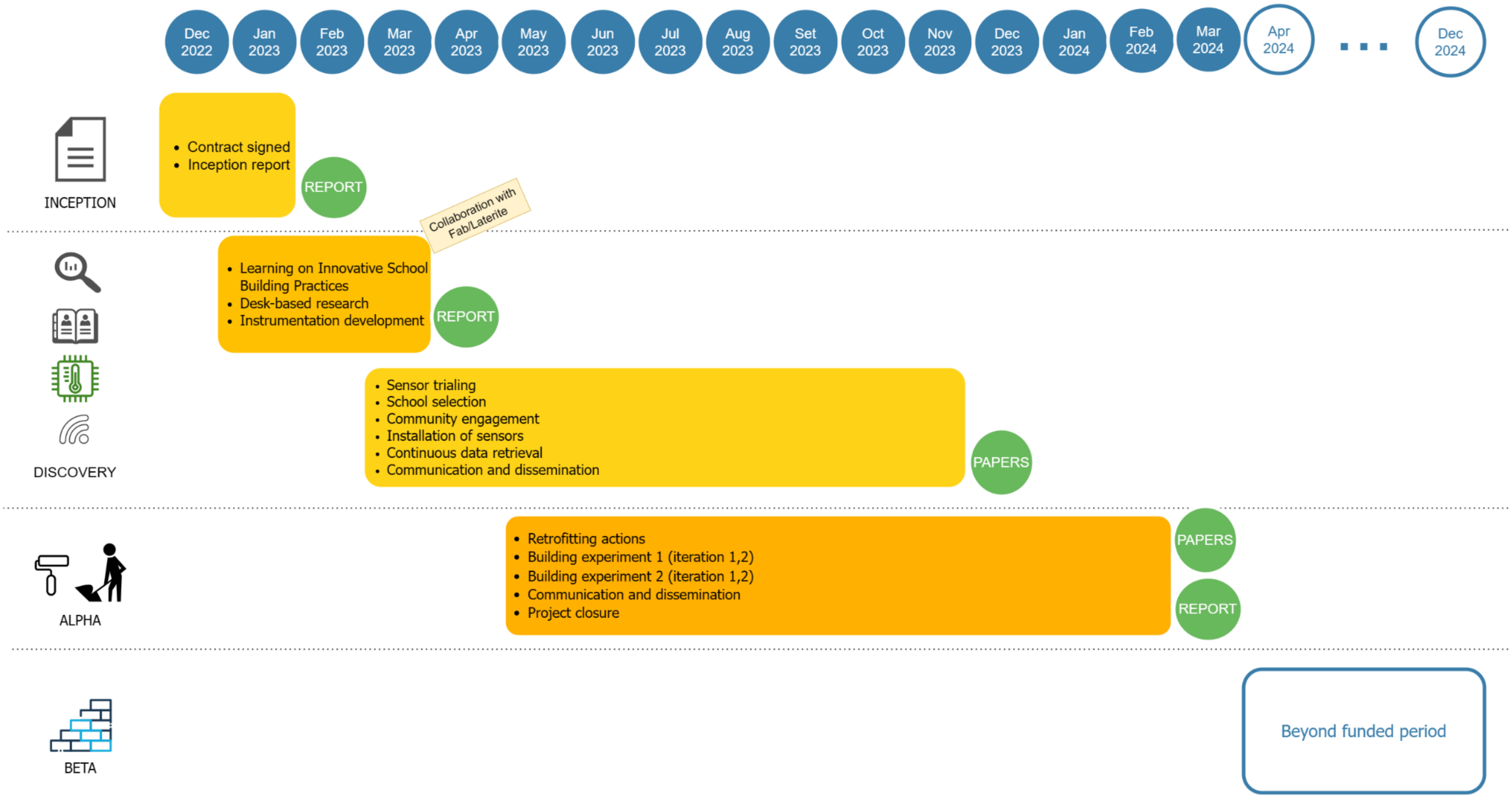
As seen in the work plan below, there is a Beta phase that goes beyond the formal funded period of this project. Our aspiration is to apply for different funds next year. Ideally, if a fund is granted, we would start planning more in-depth retrofitting actions by September or October of next year and implement those by the beginning of 2024.

4.5. Gender equality and social inclusion (GESI)

We noted above that thermal comfort has a gender dimension (↑Ahmed et al., 2022), with girls and women generally having higher temperatures of thermal comfort (↑Wang et al., 2018; during sleep: ↑Pan et al., 2012). There are also considerations relating to disabilities and adjusting thermal comfort (↑Parsons, 2002). Our analysis will pay special attention to factors of gender equality and social inclusion, and make specific recommendations. Future research (beta, beyond the funded phase) will explore additional GSCI factors, e.g. considering approaches pioneered using ↑An IoT-based deep learning approach to analyse indoor thermal comfort of disabled people (Brik et al., 2021).

In this research, we also go beyond the school itself, but also consider the distance to school (walking distance in hot climate) as well as the conditions in the home. We take note of the groundbreaking research in Tanzania on ↑What Do Tanzanian Parents Want from Primary Schools—and What Can Be Done about It? (Solomon & Zeitlin, 2019). The research shows that parents make careful choices about the education of their children, and — irrespective of socioeconomic status — are likely to be amenable to home improvement measures that will have educational outcomes for their children. This is an important area that we focus on.

5. Work plan


Dec 2022
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Aug 2023
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Nov 2023
Dec 2023
Jan 2024
Feb 2024
Mar 2024
Apr 2024
Dec 2024
INCEPTION
• Contract signed
• Inception report
REPORT
Collaboration with Fab/Laterite
DISCOVERY
• Learning on Innovative School Building Practices
• Desk-based research
• Instrumentation development
REPORT
• Sensor trialing
• School selection
• Community engagement
• Installation of sensors
• Continuous data retrieval
• Communication and dissemination
PAPERS
ALPHA
• Retrofitting actions
• Building experiment 1 (iteration 1,2)
• Building experiment 2 (iteration 1,2)
• Communication and dissemination
• Project closure
PAPERS
REPORT
BETA
Beyond funded period

6. Ethics, safeguarding, and risk management

Our evaluation team holds themselves accountable to and practices standard ethical principles that protect the privacy, confidentiality, and safety of participants and the evaluation team, child safeguarding principles (if any data is collected from children), and principles. For safeguarding data, we draw upon the principles of the Good Governance of Children's Data developed by Linda Raftree for UNICEF.

In Tanzania, a permission from the Tanzania Commission for Science and Technology (COSTECH) is required to carry out human subjects research. For work in schools, permission from the President's Office, Regional Administration and Local Government Tanzania (PO-RALG) is needed. We will obtain both permissions.

Study participants are given informed consent forms to read and sign. As minors are included in the study (albeit peripherally), their parents are informed and asked to sign a consent form on behalf of their child. We provide consent forms in both English and local languages to ensure understanding. Adults who struggle with written text should have the form read and explained to them before signing.

We store all personally identifiable data securely and GDPR-compliant using encrypted, password-protected files, and by anonymizing data before analysis. If monitoring shows any potential harm to participants as a result of participation, we consult immediately with the client/partner on further measures, including potentially halting research.

All project partners have rigorous child protection policies. We vet and train all staff and contractors to ensure their suitability to work around children, including how to safeguard the welfare of children involved in research activities. Staff and enumerators are also trained on how to report any incidents that violate the policy.

The majority of the retrofitting work will be done at a few selected school facilities during the 'Alpha' phase of our work, keeping in mind school hours and break periods to prevent disruptions to the students' education.

7. Communication and research uptake

We will produce several blogs, policy briefs, research papers (and journal articles). We will publish the setup for the research, the various aspects of classroom experience and design proposals (Discovery), as well as research papers on the combined retrofit intervention to improve learning (Alpha). Furthermore, we will also produce several policy briefs, blogs / presentations, webinars for partners and governments.

We believe that some of the strongest avenues for research uptake will be the relationships and cooperation formed during the programme itself. While the appointment of the research assistant (and funding of their future PhD research) is only a small step, it is effectively commissioning further research. Through our engagement with university partners, further avenues for research will be explored.

Through the engagement with implementers in Tanzania, including shared activities in the Alpha phase, we pave the way for research engagement to improve infrastructure programming, which will be strengthened in future phases. Further to this, our connections via UDSM (University of Dar es Salaam) and the EdTech Hub, will also engage governments and development partners.

8. Bibliography

This bibliography is available digitally in our evidence library at https://docs.opendeved.net/lib/44YQ4VEG

BME280 temperature, pressure, humidity sensor. (n.d.). Retrieved June 1, 2022, from https://ae-bst.resource.bosch.com/media/_tech/media/datasheets/BST-BME280-DS002.pdf. (details)

Burkina Faso: Why some West African architects are choosing mud over concrete (National Geographic). (2021, December 6). Barza Wire. https://wire.farmradio.fm/farmer-stories/burkina-faso-why-some-west-african-architects-are-choosing-mud-over-concrete-national-geographic/. (details)

Feather. (n.d.). Retrieved June 1, 2022, from https://www.adafruit.com/category/943. (details)

LTR-559 light and proximity sensor. (n.d.). Retrieved June 1, 2022, from https://optoelectronics.liteon.com/upload/download/ds86-2013-0003/ltr-559als-01_ds_v1.pdf. (details)

LTR390-UV-1. (n.d.). Retrieved June 1, 2022, from https://optoelectronics.liteon.com/upload/download/DS86-2015-0004/LTR-390UV_Final_%20DS_V1%201.pdf. (details)

MEMS microphone. (n.d.). Retrieved June 1, 2022, from https://media.digikey.com/pdf/Data%20Sheets/Knowles%20Acoustics%20PDFs/SPH0645LM4H-B.pdf. (details)

MICS6814 analog gas sensor. (n.d.). Retrieved June 1, 2022, from https://www.sgxsensortech.com/content/uploads/2015/02/1143_Datasheet-MiCS-6814-rev-8.pdf. (details)

PMS5003 Particulate Matter Sensor. (n.d.). Retrieved June 1, 2022, from http://www.aqmd.gov/docs/default-source/aq-spec/resources-page/plantower-pms5003-manual_v2-3.pdf. (details)

SGP40 Indoor Air Quality Sensor for VOC. (n.d.). Retrieved June 1, 2022, from https://www.mouser.co.uk/datasheet/2/682/Sensirion_Gas_Sensors_Datasheet_SGP40-2001008.pdf. (details)

SIM7600G-H 4G HAT (B). (n.d.). Retrieved June 1, 2022, from https://www.waveshare.com/wiki/SIM7600G-H_4G_HAT_(B). Available from https://www.waveshare.com/wiki/SIM7600G-H_4G_HAT_(B). (details)

SIM800C GSM/GPRS HAT. (n.d.). Retrieved June 1, 2022, from https://www.waveshare.com/wiki/SIM800C_GSM/GPRS_HAT. (details)

Ahmed, R., Ucci, M., Mumovic, D., & Bagkeris, E. (2022). Effects of thermal sensation and acclimatization on cognitive performance of adult female students in Saudi Arabia using multivariable-multilevel statistical modeling. *Indoor Air*, *32*(2), e13005. https://doi.org/10.1111/ina.13005. (details)

Barreda, S., & Assmann, P. F. (2021). Perception of gender in children's voices. *The Journal of the Acoustical Society of America*, *150*(5), 3949–3963. https://doi.org/10.1121/10.0006785. Available from https://asa.scitation.org/doi/10.1121/10.0006785. (details)

Bidassey-Manilal, S., Wright, C. Y., Engelbrecht, J. C., Albers, P. N., Garland, R. M., & Matooane, M. (2016). Students' Perceived Heat-Health Symptoms Increased with Warmer Classroom Temperatures. *International Journal of Environmental Research and Public Health*, *13*(6), 566. https://doi.org/10.3390/ijerph13060566. Available from https://www.mdpi.com/1660-4601/13/6/566. (details)

Blaker, A., & Andrew, B. (2020). *Effects of Classroom Environment on Learning*. 甲南大学マネジメント創造学部HSMR編集委員会. https://doi.org/10.14990/00003653. (details)

Boix-Vilella, S., Saiz-Clar, E., León-Zarceño, E., & Serrano, M. A. (2021). Influence of Air Temperature on School Teachers' Mood and the Perception of Students' Behavior. *Sustainability*, *13*(17), 9707. https://doi.org/10.3390/su13179707. (details)

Brik, B., Esseghir, M., Merghem-Boulahia, L., & Snoussi, H. (2021). An IoT-based deep learning approach to analyse indoor thermal comfort of disabled people. *Building and Environment*, *203*, 108056. https://doi.org/10.1016/j.buildenv.2021.108056. Available from https://www.sciencedirect.com/science/article/pii/S0360132321004583. (details)

Cartieaux, E., Rzepka, M.-A., & Cuny, D. (2011). Qualité de l'air à l'intérieur des écoles. *Archives de Pédiatrie*, *18*(7), 789–796. https://doi.org/10.1016/j.arcped.2011.04.020. Available from https://linkinghub.elsevier.com/retrieve/pii/S0929693X11001928. (details)

Haßler, B., Villavicencio Peralta, X. A., Macharia, G., Toyinbo, O., Nambatya, M., Mtebe, J., Schaffer, J., Wargocki, P., & Adam, T. (2022). *Improving Learning Through Classroom Experience in East Africa: Temperature, Lighting, and Sound Quality – Inception report* (Improving Learning Through Classroom Experience in East Africa No. 1). Open Development & Education. https://doi.org/10.53832/opendeved.0286. Available from https://docs.opendeved.net/lib/44YQ4VEG. Available under Creative Commons Attribution 4.0. (details)

Haverinen-Shaughnessy, U., & Shaughnessy, R. J. (2015). Effects of Classroom Ventilation Rate and Temperature on Students' Test Scores. *PLOS ONE*, *10*(8), e0136165.

https://doi.org/10.1371/journal.pone.0136165. Available from https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0136165. (details)

Ibhadode, O., Ajayi, O. O., Abioye, A. A., Ismaila, J., & Adekunle, A. A. (2019). An evaluation of classroom-illumination: a critical requirement for effective designing and construction of naturally-illuminated schools in Nigeria. *Progress in Industrial Ecology, an International Journal*, *13*(4), 342–372. (details)

Kapwata, T., Gebreslasie, M. T., Mathee, A., & Wright, C. Y. (2018). Current and potential future seasonal trends of indoor dwelling temperature and likely health risks in rural Southern Africa. *International Journal of Environmental Research and Public Health*, *15*(5), 952. https://doi.org/10.3390/ijerph15050952. (details)

Kazemi, M., Mackintosh, A., Ramirez, A., & Sullivan, I. (n.d.). *Guidance Note on Climate-Smart School Construction Planning (Draft for Discussion).* https://www.fabinc.co.uk/wp-content/uploads/2021/10/Guidance-Note-on-Climate-Smart-School-Construction-Planning.pdf. (details)

Lahn, B., & Lahn, B. (2021). Changing climate change: The carbon budget and the modifying-work of the IPCC. *Social Studies of Science*, *51*(1), 3–27. https://doi.org/10.1177/0306312720941933. Available from http://journals.sagepub.com/doi/10.1177/0306312720941933. (details)

Lan, L., Tang, J., Wargocki, P., Wyon, D. P., & Lian, Z. (2022). Cognitive performance was reduced by higher air temperature even when thermal comfort was maintained over the 24–28°C range. *Indoor Air*, *32*(1). https://doi.org/10.1111/ina.12916. Available from https://onlinelibrary.wiley.com/doi/10.1111/ina.12916. (details)

Lan, L., Xia, L., Hejjo, R., Wyon, D. P., & Wargocki, P. (2020). Perceived air quality and cognitive performance decrease at moderately raised indoor temperatures even when clothed for comfort. *Indoor Air*, *30*(5), 841–859. https://doi.org/10.1111/ina.12685. Available from https://onlinelibrary.wiley.com/doi/10.1111/ina.12685. (details)

Pan, L., Lian, Z., & Lan, L. (2012). Investigation of gender differences in sleeping comfort at different environmental temperatures. *Indoor and Built Environment*, *21*(6), 811–820. https://doi.org/10.1177/1420326X11425967. (details)

Parsons, K. C. (2002). The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort. *Energy and Buildings*, *34*(6), 593–599. https://doi.org/10.1016/S0378-7788(02)00009-9. Available from https://www.sciencedirect.com/science/article/pii/S0378778802000099. (details)

Porras-Salazar, J. A., Wyon, D. P., Piderit-Moreno, B., Contreras-Espinoza, S., & Wargocki, P. (2018). Reducing classroom temperature in a tropical climate improved the thermal comfort and the performance of elementary school pupils. *Indoor Air*, *28*(6), 892–904. https://doi.org/10.1111/ina.12501. Available from https://onlinelibrary.wiley.com/doi/10.1111/ina.12501. (details)

Pule, V., Mathee, A., Melariri, P., Kapwata, T., Abdelatif, N., Balakrishna, Y., Kunene, Z., Mogotsi, M., Wernecke, B., & Wright, C. Y. (2021). Classroom Temperature and Learner Absenteeism in Public Primary Schools in the Eastern Cape, South Africa. *International Journal of Environmental Research and Public Health*, *18*(20), 10700. https://doi.org/10.3390/ijerph182010700. Available from https://www.mdpi.com/1660-4601/18/20/10700. (details)

Raspberry Pi Ltd. (n.d.). *Raspberry Pi Pico*. Raspberry Pi. Retrieved June 1, 2022, from https://www.raspberrypi.com/products/raspberry-pi-pico/. (details)

Raspberry Pi Ltd. (n.d.). *Raspberry Pi Zero 2 W*. Raspberry Pi. Retrieved June 1, 2022, from https://www.raspberrypi.com/products/raspberry-pi-zero-2-w/. (details)

Solomon, S., & Zeitlin, A. (2019). *What Do Tanzanian Parents Want from Primary Schools—and What Can Be Done about It?* Research on Improving Systems of Education (RISE). https://doi.org/10.35489/BSG-RISE-RI_2019/009. Available from https://www.riseprogramme.org/publications/what-do-tanzanian-parents-want-primary-schools-and-what-can-be-done-about-it-0. (details)

Tangjuank, S., & Kumfu, S. (2011). Particle Boards from Papyrus Fibers as Thermal Insulation. *Journal of Applied Sciences*, *11*(14), 2640–2645. https://doi.org/10.3923/jas.2011.2640.2645. Available from https://www.scialert.net/abstract/?doi=jas.2011.2640.2645. (details)

Toyinbo, O. O. (2017). *Indoor environmental quality, pupils' health and academic performance* [PhD Thesis]. Itä-Suomen yliopisto. (details)

Tran, M.-T., Wei, W., Dassonville, C., Mandin, C., Wargocki, P., & Hequet, V. (2022). Development of the TAIL rating scheme for indoor environmental quality in schools. *CLIMA 2022 Conference*, 2022: CLIMA 2022 The 14th REHVA HVAC World Congress. https://doi.org/10.34641/CLIMA.2022.244. Available from https://proceedings.open.tudelft.nl/clima2022/article/view/244. Available under Creative Commons Attribution 4.0 International. (details)

Wang, Z., de Dear, R., Luo, M., Lin, B., He, Y., Ghahramani, A., & Zhu, Y. (2018). Individual difference in thermal comfort: A literature review. *Building and Environment*, *138*, 181–193. https://doi.org/10.1016/j.buildenv.2018.04.040. Available from https://www.sciencedirect.com/science/article/pii/S0360132318302518. (details)

Wargocki, P., Porras-Salazar, J. A., & Contreras-Espinoza, S. (2019). The relationship between classroom temperature and children's performance in school. *Building and Environment*, *157*, 197–204. https://doi.org/10.1016/j.buildenv.2019.04.046. Available from https://www.sciencedirect.com/science/article/pii/S0360132319302987. (details)

Wargocki, P., Porras-Salazar, J. A., Contreras-Espinoza, S., & Bahnfleth, W. (2020). The relationships between classroom air quality and children's performance in school. *Building and Environment*, *173*, 106749. https://doi.org/10.1016/j.buildenv.2020.106749. Available from https://linkinghub.elsevier.com/retrieve/pii/S0360132320301074. (details)