ESC204 | Praxis III

Request for Proposals

Improving Sustainability and Energy Management in Buildings on the African Continent

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This Request for Proposals (RFP) provides guidance towards the design and preliminary implementation of an engineering system to address challenges centred on sustainability and energy management in buildings on the African continent.

In the following sections, we provide additional information to support the Context, outline the desired Approaches teams should take to address the stated Value Proposition, and provide a preliminary set of Engineering Requirements for each approach, which any Design Concepts developed in response to this RFP must address.

Contents

1 Context: Sustainability Challenges and Opportunities for Buildings in Africa

This section provides key background and contextual information regarding sustainability challenges for buildings on the African Continent, organized into the following sections:

1.1: Energy Challenges of Building Operations
1.2: Energy Demand Dynamics in Africa
1.3: Potential and Challenges for Local Renewable Energy Generation

Innovations focused on enabling activities in buildings that promote sustainability or addressing energy management in buildings on the African continent (and beyond) align with the following United Nations Sustainable Development Goals (UNSDGs):

- UNSDG #7 Affordable and Clean Energy [1]
- UNSDG #11 Sustainable Cities and Communities [2]

1.1 Energy Challenges of Building Operations

Buildings provide shelter, support personal activities for individuals and families, and provide space for conducting various social and economic activities. They also represent a big challenge for sustainability due to the high energy demand from their operation, which includes lighting, heating, ventilation and air-conditioning (HVAC), water heating, and appliances. Of these, HVAC and water heating represent significant demand and have been identified as areas where more efforts are needed to improve sustainable energy use in building operations [3][4].

According to the International Energy Agency's (IEA) Tracking Clean Energy Progress Report 2023, in 2022 "[t]he operations of buildings account for 30% of global final energy consumption and 26% of global energy-related emissions [from energy combustion and industrial processes] (8% being direct emissions in buildings and 18% indirect emissions from the production of electricity and heat used in buildings)" [4].

These sustainability challenges must be addressed for existing buildings, through retrofits, and in the design of new buildings, while ensuring that buildings serve the purpose for those who use them. To aid in these efforts, there is a need to both understand how building operations (and user activities) affect energy demand [5][6], and to explore various ways to meet user needs at lower energy demand or through sustainable energy sources.

1.2 Energy Demand Dynamics in Africa

The African continent has a population of just over 1.4 billion [7][1]. About 56% of this population lives in informal housing. This population is expected to reach 2.4 billion in 2050 with 80% of this growth anticipated to occur in cities [8]. This growth comes with the need for new buildings both residential and commercial to provide safe housing and to support life activities.

The expected growth in Africa's population presents challenges as well as opportunities. Much of the current housing has low resilience to climate change; however, because a large amount of construction is yet to happen, there is an opportunity to design new buildings and retrofit existing

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[1] The reference provides only indivdual country numbers so the total was computed from these numbers

ones to be more sustainable and resilient to climate change [9]. Though much of the growth in population is expected to occur in cities and urban settings, it is important to consider the case of rural settings since these areas are often important for key economic activities such agriculture.

1.3 Potential and Challenges for Local Renewable Energy Generation

According to Price Waterhouse Coopers South Africa's 2021 Africa Energy Review report, based on data from the World Bank, about 42% of the African population live without electricity access accesss. This is not evenly distributed as North Africa has some of the highest access (98% electrified) and Central Africa has the lowest (30% electrified) [10]. Increasing energy access is important for getting the most value out of building operations.

According to the World Banks' Global Solar Atlas project, Africa has one the highest potentials for solar energy production. Much of this potential remains untapped as almost 90% of energy generation comes from fossil fuel sources, with less than 1% coming from solar. A focus on solar and other renewable energies has the potential to increase energy access in a sustainable way and reduce dependence on fossil fuels. Despite the high potential for solar energy, tapping this potential comes with its challenges. Local weather and dust conditions can affect effective output of panels. Terrain and local policies on land use can affect location of installations. Ease of maintenance is critical as well.

1.4 Stakeholders Summary

1.4.1 Building Occupants

For this design challenge, we will focus on residential buildings, office spaces, event and entertainment spaces, and other similar non-industrial buildings. In a residential setting, an individual or small group of people living together use various appliances that have different energy demands for various activities and to be comfortable in the space. In all settings occupants have to balance energy-saving behaviors with comfort and activities they want to engage in while using the building.

1.4.2 Building Operators

Non-residential spaces and communal residential spaces such apartment buildings often have building managers. These people make decisions about resources required to operate the building and how to provide a space that is most conducive to the goals of the use of the building. Building managers have to balance any building management decisions that lead to reduced energy demand (or increased local renewable energy generation) with the needs and preferences of building occupants.

1.4.3 Government and Policy makers

Policies play an important role in shaping the behavior of the various stakeholders as relates to energy dynamics of buildings. Development of policies and programs happens at multiple levels from local communities, to municipalities to regional and local governments. In addition, governments often collaborate with non-governmental organization on policy development. The higher (more national) levels of government can constrain the policy options the lower (more local) levels have.

While an understanding of the dynamics of energy dynamics is important for policy makers, they also have to understand the lived experience and cultural and social norms of the communities that policies may affect to ensure better policy adoption. Furthermore, governments may have to contend with special interests and influence from those external to their communities (e.g., policy mandates that are attached to investments from foreign governments [11] or global organizations such as the International Monetary Fund (IMF) [12]). Often, especially at the local level, policy makers are themselves also members of the communities they serve.

1.4.4 Technology Developers

Technology developers support other stakeholders by providing a number of different solutions to meet various needs. They are guided by policy incentives that shape technology development and adoption, as well as early feasibility explorations of researchers or early concept ideas from design challenges. Data on the dynamics of energy use is especially important to technology developers as it allows to them to understand how new technologies can impact various stakeholders. Technology developers also need an understanding of building design and development to know what can be feasibly incorporated into new buildings or as retrofits to existing buildings. Our locations of interest tend to have more developing economies where goods need to have reasonable price points in order to be more widely accessible to various stakeholders. There may be also limitations on access to certain materials and resources for technology development.

1.4.5 Building Designers and Developers

Buidling designers and developers play a role in providing new buildings or renovating existing ones to meet the needs of building occupants and operators in ways that are aligned with policy. They also play a key role in incorporating new technologies that help with energy demand reduction or energy generation to give occupants and operators options for managing energy use.

1.5 Value Proposition

Buildings support essential activities which create energy demands. Enabling and/or empowering communities to lower these energy demands, or to offset energy use by leveraging local renewable generation will help with improving sustainability as it relates to building use.

2 Preferred Approaches: Mechatronics and IoT

In the context of ESC204, we will take two distinct sets of approaches to addressing this value proposition. One is a set of approaches based in Mechatronics (i.e., building a sensor-actuator system), while the other centres Internet-of-Things (IoT) approaches (i.e., building a networked collection of distributed sensors and/or actuators) to help you achieve the Learning Outcomes related to hands-on prototyping for this course. The two sets of approaches are briefly outlined in the following sections.

2.1 Mechatronic Approaches: Reduced Energy Use to Support Various Activities

Recommendations to tackle energy use for various activities in buildings include addressing lighting, heating and hot water, and cooling [4](see “Lighting”, “Heating”, and “Space Cooling” under “In this Sector”). To support building occupants in going about their activities while reducing energy use, we solicit designs that leverage natural processes (*e.g.*, natural light, heat sources, or heat sinks) and/or adapt to environmental conditions to ensure that energy from the grid is only used when necessary (*i.e.*, when other natural processes are not available) to provide these amenities that support occupants activities.

2.1.1 Engineering Requirements

Design Concepts developed in response to this RFP, and in particular, the Mechatronic approach described in Section 2.2 should address the Engineering Requirements given in Tables 1 and 2.

Table 1: Functional Objectives for any Design Concepts which take the Mechatronic Approach focused on Reducing Energy Use to Support Various Activities to addressing the Value Proposition.

Objectives		Metrics	Constraints	Criteria
Functional Objectives: Design concepts will...				
FO-1	Provide occupant needs (lighting, heating, cooling, hot water) using natural processes	Method of providing needs based on natural processes [13].	Must leverage one or more methods in ENERGY STAR checklist linked to leveraging natural process (e.g. lighting, heat flow into and out of the building, etc.)	More methods is preferred.
FO-2	Provide occupant needs (lighting, heating, cooling, hot water) to sufficient level	Metric associated with particular need: 1. Heat Index (°C) [14] [15] for cooling 2. Temperature (°C) for heating 3. Temperature (°C) hot water 4. Illuminance (lux) for lighting [16] (desired temperature for heating, cooling, and hot water, and).	Thresholds associated with associated need: 1. < 27°C for cooling [15] 2. > 18°C (°C) for heating [17] 3. > 60°C (°C) for hot water[18] 4. > 300 lux for lighting [16]	Further from the threshold is preferred.
FO-3	Reduce grid energy consumption of the building.	Energy [kWh] consumed by building	Must reduce energy relative to status quo (i.e., without use of the design).	Less energy consumed is preferred.

Table 2: Performance Objectives for any Design Concepts which take the Mechatronic Approach focused on Reducing Energy Use to Support Various Activities to addressing the Value Proposition.

Objectives		Metrics	Constraints	Criteria
Performance Objectives: Design Concepts should...				
PO-1	Improve grid energy consumption of the building.	Energy [kWh] consumed by building		Less energy consumed is preferred.
PO-2	Minimize power required for operation.	Average power [W] consumed by the design while operating.		Less power consumed is preferred.
PO-3	Operate quietly.	Sound Power (dBA) produced by the design while in operation.		Lower sound power is preferred.
PO-4	Be easy to use.	Consideration of factors leading to users 1) understanding and 2) effectively handling the design (as in Chapter 3.7 of [19], for example)		User-facing elements of the design (if any) should clearly indicate how a user can/should interact with the design.
PO-5	Be safe for the user.	Mitigation of Hazards and Risks associated with operation following a Hierarchy of Controls methodology (e.g., [20]).		Designs prioritizing more effective hazard control (as in [20]) are preferred.

2.2 Mechatronic Approaches: Mitigate Environmental Effects on Performance of Renewables

[2] According to Price Waterhouse Coopers South Africa's 2021 Africa Energy Review report, based on data from the World Bank, while unevenly distributed, on average, about 42% of the African population live without electricity access [10]. Increasing energy access is important for getting the most value out of building operations. According to the World Banks' Global Solar Atlas project, Africa has one the highest potentials for solar energy production. Much of this potential remains untapped as almost 90% of energy generation comes from fossil fuel sources, with less than 1% coming from solar [10]. Despite the high potential for solar energy, tapping this potential comes with its challenges. Local weather and dust conditions can affect effective output of panels [21]. Terrain and local policies on land use can affect location of installations [22][21]. Ease of maintenance is critical as well [23]. Therefore, we solicit designs which reduce the impact of environmental effects on either existing or newly installed solar power systems, to improve feasibility and promote adoption of these technologies.

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[2] This approach was inspired by work done by previous teams in the course

2.2.1 Engineering Requirements

Design Concepts developed in response to this RFP, and in particular, the Mechatronic approach described in Section 2.2 should address the Engineering Requirements given in Tables 3 and 4.

Table 3: Functional Objectives for any Design Concepts which take the Mechatronic Approach focused on Mitigating Environmental Effects on Performance of Renewables to addressing the Value Proposition.

	Objectives	**Metrics**	**Constraints**	**Criteria**
Functional Objectives: Design concepts will...				
FO-1	Remove particles that obstruct sunlight from contacting solar panel	Dusty density after cleaning [mg/cm^2] [24]	$< 2 mg/cm^2$ [24]	Less dust preferred.
FO-2	Mitigate effect of their presence on sunlight contacting solar panel	Reduction in sunlight coverage area during operation [%]	$< 5\%$	Less reduction in sunlight coverage preferred.

2.3 IoT Approaches

Any changes to buildings and their operations to achieve sustainability goals must ensure that buildings serve the purpose for those who use them. To aid in these efforts, there is a need to both understand how building operations (and user activities) affect energy demand [5][6]. This information can be useful for helping operators plan energy management as part of building operations or to manage energy in real-time; for educating building users about behaviors and effects on energy use to to support behavior change; or to help policy makers enact policies that encourage improved energy demand from building use while adequately supporting users' activities [4] (See "Recommendations"). We solicit designs that provide information that help understand the relationships between environmental factors, building occupants needs and activities, and resulting energy demand.

2.3.1 Engineering Requirements

Design Concepts developed in response to this RFP, and in particular, the Mechatronic approach described in Section 2.2 should address the Engineering Requirements given in Tables 5 and 6.

Table 4: Performance Objectives for any Design Concepts which take the Mechatronic Approach focused on Mitigating Environmental Effects on Performance of Renewables to addressing the Value Proposition

	Objectives	**Metrics**	**Constraints**	**Criteria**
Performance Objectives: Design Concepts should...				
PO-1	Remove particles that obstruct sunlight from contacting solar panel	Dusty density after cleaning [mg/cm^2] [24]		Less dust preferred.
PO-2	Minimize power required for operation.	Average power [W] consumed by the design while operating.		Less power consumed is preferred.
PO-3	Operate quietly.	Sound Power (dBA) produced by the design while in operation.		Lower sound power is preferred.
PO-4	Be easy to use.	Consideration of factors leading to users 1) understanding and 2) effectively handling the design (as in Chapter 3.7 of [19], for example)		User-facing elements of the design (if any) should clearly indicate how a user can/should interact with the design.
PO-5	Be safe for the user.	Mitigation of Hazards and Risks associated with operation following a Hierarchy of Controls methodology (e.g., [20]).		Designs prioritizing more effective hazard control (as in [20]) are preferred.

Table 5: Functional Objectives for any Design Concepts which take the IoT Approach to addressing the Value Proposition.

	Objectives	**Metrics**	**Constraints**	**Criteria**
Functional Objectives: Design concepts will...				
FO-1	Collect data related to energy use, and either occupancy and general occupant behavior or external environmental factors	Types of data collected [5][6]	Must collect data on energy use and one other variable that affects energy use	More distinct data type(s) are preferred.
FO-2	Communicate data to relevant users (building occupants, building operators, policy makers)	Availability of data to the user [uptime for communication].	Must communicate data.	If designs are for building users, those that enable real-time/on-demand communication are preferred. If designs are for policy makers, those that have more distinct types of data that can be related to each other are preferred.
FO-3	Store data for later retrieval and analysis.	Data history length [months].	> 12 months [25] (try countries in Africa)	Longer data history lengths are preferred.

Table 6: Performance Objectives for any Design Concepts which take the IoT Approach to addressing the Value Proposition

	Objectives	Metrics	Constraints	Criteria
Performance Objectives: Design Concepts should...				
PO-1	Collect data at high time resolution	Inter-sample period [min]		Smaller inter-sample periods preferred.
PO-2	Minimize power required for operation.	Average power [W] consumed by the design while operating.		Less power consumed is preferred.
PO-3	Operate quietly.	Sound Power (dBA) produced by the design while in operation.		Lower sound power is preferred.
PO-4	Be easy to use.	Consideration of factors leading to users 1) understanding and 2) effectively handling the design (as in Chapter 3.7 of [19], for example)		User-facing elements of the design (if any) should clearly indicate how a user can/should interact with the design.
PO-5	Be safe for the user.	Mitigation of Hazards and Risks associated with operation following a Hierarchy of Controls methodology (e.g., [20]).		Designs prioritizing more effective hazard control (as in [20]) are preferred.

3 Opportunity Champions

Mona Mohammed: Mona is a Programme Management Officer at the United Nations Environment Programme (UNEP) based in Paris, France. Through the Life Cycle Initiative, Mona works on increasing access to Life Cylce Analysis (LCA) data, life cycle knowledge, and harmonized methodology for public and private stakeholders, including within UNEP, to implement sustainable consumption and production (SCP) strategies. In her role, she works closely with the Building and Construction, and the Mining and Extractives high impact sectors. Mona's background is in Environmental Engineering and Women and Gender Studies. Before joining the UN, Mona worked as a water, sanitation, and hygiene (WASH) Advisor supporting the Humanitarian response in Yemen and Sudan. Mona provided that initial resources and input that were the basis of the first version of the RFP for this design space.

Amma Oforiwaa Ampomah Asiedu: Amma is an engineer in training in the IP network planning division of MTN Ghana, the Ghanaian subsidiary of the multinational telecommunication company MTN Group. Amma has a background in Electrical and Electronic Engineering and a keen interest in wireless communication and home automation, where she has explored entrepreneurial projects in smart home innovations that enable sustainable living solutions. Amma provided input into the development of the revised version of the RFP.

Nigel Derby: Nigel is the Founder of Capsule Africa, a dedicated contractring firm specializing in the design and construction of modern container homes in Ghana, blending creativity with sustainability. Committed to innovation, he is interested in integrating cutting-edge sustainable practices in buildings, including cladding with vertical garden systems, rainwater harvesting, and energy-efficient insulation, to reduce environmental impact without compromising comfort or quality. Nigel provided input into the development of the revised version of the RFP.

References

[1] United Nations Department of Economic and Social Affairs, *United Nations Sustainable Development Goals 7: Affordable and Clean Energy*. [Online]. Available: https://sdgs.un.org/goals/goal7.

[2] United Nations Department of Economic and Social Affairs, *United Nations Sustainable Development Goal 11: Sustainable Cities and Communities*. [Online]. Available: https://sdgs.un.org/goals/goal11.

[3] UNEP, "2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector," United Nations Environment Programme, Nairobi, Tech. Rep., 2022. [Online]. Available: https://globalabc.org/resources/publications/2022-global-status-report-buildings-and-construction.

[4] International Energy Agency, *Energy System: Buildings*. [Online]. Available: https://www.iea.org/energy-system/buildings.

[5] A. G. Dagnachew, S.-M. Choi, and G. Falchetta, "Energy planning in Sub-Saharan African countries needs to explicitly consider productive uses of electricity," *Scientific Reports*, vol. 13, no. 1, p. 13 007, Aug. 2023, ISSN: 2045-2322. DOI: 10.1038/s41598-023-40021-y.

[6] V. Daioglou, B. J. van Ruijven, and D. P. van Vuuren, “Model projections for household energy use in developing countries,” *Energy*, vol. 37, no. 1, pp. 601–615, Jan. 2012, ISSN: 03605442. DOI: 10.1016/j.energy.2011.10.044.

[7] Economic Commission for Africa, African Development Bank Group, and African Union Commission, “The African Statistical Yearbook 2021,” Tech. Rep., 2022. [Online]. Available: https://www.afdb.org/en/documents/african-statistical-yearbook-2021.

[8] AfDB, “Tracking Africa’s Progress in Figures,” Statistics Department, African Development Bank Group, Tunis, Tech. Rep., 2014. [Online]. Available: https://www.afdb.org/en/knowledge/publications/tracking-africa%E2%80%99s-progress-in-figures.

[9] M. M. Gambo, *Enhancing climate adaptation: The role of climate resilient housing in Africa’s cities*, 2023. [Online]. Available: https://www.brookings.edu/articles/enhancing-climate-adaptation-the-role-of-climate-resilient-housing-in-africas-cities/.

[10] PWC, “Africa energy review,” Price Waterhouse Cooper, Tech. Rep., 2021. [Online]. Available: https://www.pwc.com/ng/en/assets/pdf/africa-energy-review-2021.pdf.

[11] V. Collingwood, “Assistance with Fewer Strings Attached,” *Ethics & International Affairs*, vol. 17, no. 1, pp. 55–67, 2003, ISSN: 1747-7093. DOI: 10.1111/J.1747-7093.2003.TB00418.X. [Online]. Available: https://www.cambridge.org/core/journals/ethics-and-international-affairs/article/abs/assistance-with-fewer-strings-attached/3761F53A5EEAD173BD1B3D6DEAF511C8.

[12] International Monetary Fund, *Economic Surveillance*. [Online]. Available: https://www.imf.org/external/pubs/ft/ar/2022/what-we-do/economic-surveillance/.

[13] “Checklists of energy-saving measures,” ENERGY STAR Program, United States Environmental Protection Agency, Tech. Rep., 2021. [Online]. Available: https://www.energystar.gov/buildings/save-energy-commercial-buildings/ways-save/checklists.

[14] National Weather Service, *Heat Forecast Tools*. [Online]. Available: https://www.weather.gov/safety/heat-index.

[15] J. Teare, A. Mathee, N. Naicker, *et al.*, “Dwelling characteristics influence indoor temperature and may pose health threats in LMICs,” *Annals of Global Health*, vol. 86, no. 1, pp. 1–13, 2020, ISSN: 22149996. DOI: 10.5334/AOGH.2938.

[16] I. Konstantzos, S. A. Sadeghi, M. Kim, J. Xiong, and A. Tzempelikos, “The effect of lighting environment on task performance in buildings – A review,” *Energy and Buildings*, vol. 226, p. 110 394, Nov. 2020, ISSN: 0378-7788. DOI: 10.1016/J.ENBUILD.2020.110394.

[17] H. Janssen, K. Ford, B. Gascoyne, *et al.*, “Cold indoor temperatures and their association with health and well-being: a systematic literature review,” *Public Health*, vol. 224, pp. 185–194, Nov. 2023, ISSN: 0033-3506. DOI: 10.1016/J.PUHE.2023.09.006.

[18] WHO, “WHO Housing and health guidelines, Recommendations to promote healthy housing for a sustainable and equitable future,” *Department of Housing and Urban Development*, p. 149, 2018. [Online]. Available: Available%20at%20https://www.who.int/publications/i/item/9789241550376.

[19] R. T. Klooster, F. Lox, and T. Schilperoord, *Packaging Design Decisions - A Technical Guide*. DEStech Publications, 2019, ISBN: 978-1-60595-070-9. [Online]. Available: https://app.knovel.com/hotlink/toc/id:kpPDDATG03/packaging-design-decisions/packaging-design-decisions.

[20] Canadian Centre for Occupational Health and Safety. "Hazard and Risk – Hierarchy of Controls." (), [Online]. Available: https://www.ccohs.ca/oshanswers/hsprograms/hazard/hierarchy_controls.html. (accessed: 01.23.2025).

[21] O. Bamisile, C. Acen, D. Cai, Q. Huang, and I. Staffell, "The environmental factors affecting solar photovoltaic output," *Renewable and Sustainable Energy Reviews*, vol. 208, p. 115 073, Feb. 2025, ISSN: 1364-0321. DOI: 10.1016/J.RSER.2024.115073.

[22] J. Carrilho, G. Dgedge, P. M. P. d. Santos, and J. Trindade, "Sustainable land use: Policy implications of systematic land regularization in Mozambique," *Land Use Policy*, vol. 138, p. 107 046, Mar. 2024, ISSN: 0264-8377. DOI: 10.1016/J.LANDUSEPOL.2023.107046.

[23] R. Chidembo, J. Francis, and S. Kativhu, "Underlying beliefs that influence solar home system adoption in Vhembe district Municipality, South Africa," *Social Sciences & Humanities Open*, vol. 9, p. 100 754, Jan. 2024, ISSN: 2590-2911. DOI: 10.1016/J.SSAHO.2023.100754.

[24] S. Z. Said, S. Z. Islam, N. H. Radzi, C. W. Wekesa, M. Altimania, and J. Uddin, "Dust impact on solar PV performance: A critical review of optimal cleaning techniques for yield enhancement across varied environmental conditions," *Energy Reports*, vol. 12, pp. 1121–1141, Dec. 2024, ISSN: 2352-4847. DOI: 10.1016/J.EGYR.2024.06.024.

[25] U. S. E. P. A. ENERGY STAR Program, *ENERGY STAR Portfolio Manager Portfolio Manager: What data is required to benchmark your property?* [Online]. Available: https://portfoliomanager.energystar.gov/pm/dataCollectionWorksheet.