

METABOX: A PROGRAMMABLE CONVECTION-GATED THERMAL STORAGE PLATFORM FOR RETROFIT-READY BUILDINGS

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This project introduces **MetaBox**, an innovative **convection-gated phase change material (PCM) module** that transforms latent thermal storage from a passive component into a programmable HVAC asset. By dynamically controlling buoyancy-driven convection inside the PCM through **geometric reconfiguration**, the system can switch between a low-loss “Hold mode” for energy storage and a high-power “Power mode” for rapid thermal delivery. This ability to decouple thermal energy capacity from power output directly addresses a long-standing limitation that has hindered the adoption of PCM technologies in real HVAC systems.

The research responds to an urgent regional challenge: buildings in Lebanon face persistent electricity shortages, high cooling demand, and heavy reliance on backup generation, yet most of the building stock cannot undergo deep energy retrofits. MetaBox is designed specifically for this reality. It is a compact, retrofit-ready module that integrates into existing HVAC air systems to provide thermal buffering, reduce peak electrical demand, and enhance comfort resilience during supply interruptions.

Over a two-year period, the project will establish the scientific basis of convection gating, develop and fabricate a modular MetaBox prototype, and experimentally validate its performance under HVAC-relevant conditions. The work will quantify controllable thermal power, assess operational robustness, and produce deployment-oriented design rules that enable future scaling and industry transfer. Beyond technical validation, the project will prepare the MetaBox technology for real-world adoption by developing a pilot-ready deployment pathway informed by human-centered design and secured through a patent-backed intellectual property strategy.

By introducing a new class of programmable thermal storage, this project advances both fundamental heat-transfer science and applied building technology. Its outcomes position AUB at the forefront of climate-responsive energy innovation while delivering a scalable solution for energy-constrained regions. MetaBox has the potential to convert conventional HVAC systems into flexible thermal resources, supporting peak-load reduction, better use of distributed solar energy, and a more resilient built environment.