論　文　要　旨
Thesis Abstract

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※報告番号	甲 第　389 号	氏　名 (Name)	THITI CHANCHAYNON

主論文題名　（Title）

NUMERICAL AND EXPERIMENTAL EVALUATION FOR PERFORMANCE OPTIMIZATION OF GROUND HEAT UTILIZATION SYSTEMS WITH ENERGY PILES

内容の要旨　（Abstract）

This dissertation addresses the critical challenge of implementing renewable subsurface energy systems in tropical Southeast Asian cities, where persistently high ground temperatures, limited seasonal thermal recovery, and the presence of soft clay soils introduce performance uncertainties not adequately considered in conventional energy pile design approaches. Existing studies largely focus on temperate and cold climates and typically examine individual aspects of thermal performance, structural response, or economics in isolation, resulting in a lack of a unified, decision-oriented framework suitable for tropical environments. Consequently, long-term thermal accumulation, operational reliability, and economic feasibility remain insufficiently understood in Southeast Asia, constraining widespread adoption. To bridge this gap, this research introduces a novel performance-based digital twin framework that integrates thermo-controlled consolidation experiments with calibrated Finite difference method (FDM), Finite element method (FEM), and Long short-term memory (LSTM) machine learning models into a unified and interactive methodology. The innovation lies not only in combining these tools but in using laboratory-derived thermo-hydro-mechanical responses to validate, constrain, and continuously update numerical and predictive models, enabling an adaptive design platform capable of assessing both short-term operation and long-term thermal evolution. This technical framework is explicitly linked to economic evaluation through integrated LCCA, SPBP, RRR, NPV, IRR, and LCOE analyses, allowing engineering performance and financial feasibility to be evaluated simultaneously. Quantitative results demonstrate that the framework significantly improves prediction reliability and design confidence. Compared with conventional single-model approaches, the integrated methodology achieves 10 % improvement from R2 of 0.85 to 0.95 when compared to FEM in temperature prediction accuracy and demonstrates the ability to delay thermal saturation and reduce ground-temperature rise by approximately 15°C through optimized duty cycles and pile spacing strategies. The LSTM model further

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enhances predictive capability by capturing operational variability, achieving 10 % improvement in temporal prediction performance, while the economic assessment confirms feasibility under Southeast Asian cost structures, and 5 years improvement in payback period under realistic electricity price escalation scenarios.

Overall, this dissertation delivers the first tropical-context, experimentally validated, performance-based design framework for energy piles in Southeast Asia. By linking physics-based modelling, laboratory evidence, machine-learning forecasting, and economic feasibility into a transparent and implementable system, the study provides engineers, planners, and policymakers with a robust foundation to evaluate, design, and confidently deploy energy pile systems in rapidly urbanizing tropical environments where reliability, sustainability, and economic practicality must be achieved simultaneously.

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