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学位論文題目	Optimizing Indoor Thermal Environments for Enhanced Energy Performance in the Buildings （室内熱環境の最適化及び建築のエネルギー高効率化に関する研究）
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論文内容の要旨

The growing demand for indoor thermal comfort, driven by advancements in living standards and economic growth, has led to a substantial increase in energy consumption. This trend has prompted global efforts to reduce energy use while ensuring comfort through optimized building design, improved envelopes, and efficient HVAC control. However, achieving energy efficiency in traditional Japanese wooden houses presents unique challenges due to their distinct physical characteristics and cultural preservation requirements. Similarly, in Nepal, the lack of established energy codes or standards complicates efforts to guide energy efficiency improvements, whether for new construction or retrofitting. Given the shared objective of enhancing energy performance while ensuring occupant comfort, this research investigates the thermal performance and retrofit potential of traditional Japanese wooden houses and Nepalese concrete structures, providing a comparative study across two geographically and structurally distinct contexts.

Typical thermal performance assessments rely on physics-based models, which require detailed knowledge of material properties. However, in energy retrofit projects, where traditional material properties are often unavailable and rapid predictions are crucial, machine learning models like Support Vector Regression (SVR) and Random Forest Regression (RFR) are used to predict complex thermal behaviors, including solar absorbance and indoor temperature variations. While many previous studies on ML models utilize data collected from multiple sensors over extended periods across various features, this approach is often impractical for renovation or retrofitting projects due to short construction timelines. Therefore, this study proposes a thermal performance assessment method that is not only accurate and reliable but also computationally efficient, representing a crucial step toward optimizing energy efficiency in buildings.

In the context of Nepal, this study examines the thermal performance of vegetated and non-vegetated buildings in the Kathmandu Valley, focusing on comparisons of indoor and outdoor temperatures, thermal transmittance, solar absorbance, and predictive modeling using machine learning techniques. Results indicate that the vegetated wall structure significantly enhances thermal resistance, resulting in lower indoor temperatures with a more stable thermal environment compared to the non-vegetated building, which exhibited higher indoor temperatures due to its reduced heat-buffering capacity. The use of vegetation in this setting effectively reduced solar absorbance, improved thermal regulation, and demonstrated the potential of vegetated facades to mitigate heat gain and maintain cooler indoor environments. These findings are particularly relevant for Kathmandu, an emerging urban area where the demand for operational energy is rising due to lifestyle changes.

In the context of Japan, traditional wooden houses are integral to the nation’s cultural heritage, making it essential to continue their use without increasing energy burdens. This study initially examined the thermal environment of well-preserved traditional Japanese wooden houses across summer and winter months, that reveals extreme thermal conditions of building envelopes and flooring in winter. Based on this, we focused on winter measurements to establish a novel approach for assessing indoor thermal performance, utilizing in-situ thermal measurements and machine learning predictive models. Two ML models (SVR and RFR) were developed to predict indoor temperatures based on the external factors and their adjacent rooms temperature. The result revealed significant thermal influence between adjacent rooms, potentially driven by heat transfer behavior. To delve deeper into these interactions, thermal images of each room were analyzed after the AC was in use. Thermal imaging highlighted the presence of hot and cold spots within the gap of sliding fusuma and ranma, illustrating significant heat transfer between the AC and non-AC rooms. This research proposes a practical, reliable approach that enables residents to prioritize thermal upgrades for efficient, cost-effective renovations.

Further, this study explored the actual thermal conditions in a renovated kominka (traditional Japanese house) located in the same region during winter, focusing on indoor conditions with and without AC usage. Results indicated that, even after renovations, the building's thermal comfort remained suboptimal both day and night without AC, and vertical temperature differences revealed inefficient heat distribution within rooms. A temperature gradient of over 10 °C was recorded, with tatami flooring at approximately 12 °C, potentially causing discomfort, particularly in occupants’ feet, even when AC was in use. With the renovation costs estimated at around 150 million yen, the findings suggest that inadequate insulation may impose an additional annual energy cost burden, thus underscoring the importance of effective thermal design in traditional Japanese buildings.

In summary, this thesis investigates how data-driven models can provide efficient and accurate methods for assessing building thermal performance in renovation or retrofitting projects over limited construction time in both Japanese and Nepalese contexts, where conventional methods may be less practical. Additionally, highlighting the actual thermal conditions of newly renovated kominka reveals inefficient heat distribution within the rooms. This raises the question of whether incorporating an understanding of thermal behavior through machine learning methods during renovations could lead to more effective thermal design for these buildings.

論文審査結果の要旨

本論文は、建築物の断熱性能などを含む熱環境評価及び予測手法の確立を目的に、緻密な建築物の熱環境調査を行い、それらの結果に対し機械学習を用いることにより、これまでに評価及び特定が難しかった建物の熱環境予測及び断熱性能評価について予測できることを示し、まとめたものである。

調査の対象は、夏期及び冬季における日本の伝統的木造住宅を中心に、気候の異なるネパールの建築において、緑化壁面の室内熱環境への影響や、遮熱性についても調査及び評価を行っており、特に、断熱性が低いことが指摘されている日本の伝統的木造住宅での熱環境評価は、これまでに調査事例が少なく、リノベーション事例についても調査を行っている点は、有意義であり、学術上においても価値があると考えられる。また、ネパールにおける建築物の壁面緑化が室内の熱環境に及ぼす影響を調査においては、壁面緑化による熱吸収性への影響について評価方法を提案し、分析を行っている。

さらに、これらの熱環境調査結果と機械学習手法を用いることにより、これまでに評価及び特定が難しかった建物の熱環境予測及び断熱性能評価について予測できることを示した。
これらの成果は、既存の手法では対応できない建物の熱的性能の評価において、本論文で提案するデータ駆動型熱環境予測モデルが効率的で精度の高い手法であることを示している。本手法を様々な建築物に拡張・適用することにより、今後、建築における熱環境改善及びエネルギー効率の高いデザインの実現が可能になると考えられる。
室内の熱環境を最適化するための実用的な知見を得ており、歴史的な建築や、景観保存の観点からもエネルギー効率と建築保存の両立を実現するための取り組みと言える。

以上のように、本論文は、建築における室内環境及びエネルギー消費効率化のため調査並びに予測手法の確立を目的に、緻密な熱環境調査結果を実施取りまとめるだけでなく、機械学習を用いて予測する手法を提案し、それらの有効性を検証したもので、学術的にも実務的にも非常に有用な研究である。

以上のことから、本論文は建築環境分野だけでなく、社会の持続可能性に貢献し得るという観点から、学術上も実際上においても寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。