Review Paper: Transfer learning applications in Smart buildings

Abstract
This review paper dealt with the applications of Transfer Learning in smart buildings. Transfer learning, in basic terms, involves transferring the knowledge of a system gained by a machine learning or reinforcement learning model to another target that may not be rich in data. Hence, Transfer learning not only speeds up the process of training Machine Learning models exponentially, but it also helps Machine Learning for systems that may not have a lot of data. In this review paper, we went over 77 research papers published in this field and tried to provide a detailed understanding of various aspects of Transfer Learning, its types, its advantages, disadvantages, use cases, metrics, and several other topics.

Introduction
An application of Machine Learning demonstrating potentially large benefits is the development and application of reinforcement learning based building controls to optimize performance of energy efficiency, energy flexibility and climate resilience of individual buildings and district of buildings. However, collecting and preparing a large amount of high-quality data to train machine learning algorithms is time consuming and not always feasible as most buildings lack reliable sensing or metering systems or lack the IT infrastructure to collect and store the data. Therefore, machine learning techniques have not been widely adopted by the industry; they are often limited to research or early-stage demonstration projects. To address this gap, one key method is to transfer machine learning models trained and validated for buildings with rich data to buildings with limited or poor data. This motivation in mind and the fact that no in-depth literature review on transfer learning exist, we aim to conduct a comprehensive and structured re-view on transfer learning, focusing on how it is used for modelling, prediction, performance diagnosis, and performance optimization of commercial and residential buildings. This review aims to provide insights into the following significant questions on transfer learning for buildings research and applications:

- Why type of transfer learning is needed for buildings research?
- What are use cases of transfer learning in buildings research?
- What are algorithms used in transfer learning?
- How to evaluate performance of transfer learning?
- What are tools or platforms for testing and benchmarking transfer learning?
- What are the challenges of transfer learning?
- How does transfer learning integrate into the AI/ML ecosystem for buildings research?
- What are future research opportunities?

Results of the Review
The figure below shows an overview of different types of Transfer learning (TL) that we have covered in our Review literature.

There are two other ways to categorize TL. One is Homogenous vs Heterogenous. Homogenous TL is when the source and target buildings have the same input features, and Heterogenous TL is when they don’t.

Another method is by looking at the task. Inductive Learning is when the source and target task are different, like predicting different quantities. Transductive Learning is when both tasks are the same.

Using these categories, we attempted to give a deeper understanding of Transfer Learning to the reader of the review paper.

The results of the review were divided into the following: Metadata analysis, Applications, and Metrics. Metadata analysis involved charts and infographics about keyword analysis, geographical distribution of authors, distribution over years and journals of published articles, application distribution over years, application distribution by topic. “Applications” section discussed how TL is specifically used for its five main application areas – load, control, dynamics, occupancy, and others. “Load” involves using TL for for things like electricity consumption forecasting, and modelling consumption and efficiency characteristics. “Control” involves using TL to model and make the control systems like HVAC and ventilation more energy efficient based on other data. “Occupancy” involves understanding occupancy characteristics of a building and using ML and TL to run the control systems in a manner that saves energy. The Metrics section – which I was responsible to write – covered the range of metrics that were used to measure performance of these TL models. I divided the TL papers into two main categories – papers that dealt with classification problem and papers that dealt with some type of regression problem – and discussed the main metrics used for both. Metrics ranged from simple accuracy and RMSE to other forms of MSE, MAPE, MAE, correlation coefficients, silhouette analysis, etc.

Methods
We need to find all relevant works in the field of transfer learning applied to buildings. The first step was to use Scopus search engine to identify and select relevant papers using the keywords:

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Furthermore, a Sub-keyword Synonym Searching (SSS) was performed to cover the most common terminology of ML and TL in buildings. The aim of the SSS method is to exhaust relevant papers by searching literature using effective keywords, synonyms and combinations. As an example, “building load prediction” can be referred to as “energy forecast in buildings”. Therefore, this paper exploited domain expertise to identify the main applications of ML in buildings (Load Prediction, Occupancy Detection, Building Dynamics, Building Systems Control), while not losing generality.

For “load prediction”, the SSS methodology combines different keywords, exploring all possible combinations among subsets of TL: Domain Adaptation, Building, Home, District, City Consumption, Electricity, Energy, Load, and Forecasting. Prediction. As a result, the iterative procedure will search for 2x4x4x2 = 64 keywords for load prediction, 24 keywords for occupancy detection, 32 keywords for building dynamics and 32 keywords for building systems control.

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Lastly, papers were manually filtered according to relevance, while preferring journal articles over conference articles when dealing with similar topics. The extracted papers were manually reviewed, categorized and organized in 5 categories, henceforth called: “Building Load Prediction”, “Occupancy Detection”, “Building Dynamics”, “Building Systems Control” and “Other”, with the latter that includes all the possible applications of TL in buildings not included in the previous categories.

Conclusions
While we are yet to write a concrete Conclusion section in our paper, my experience going over 30+ papers has provided me with some insights: (1) There’s a lot of different methods for different applications, so there’s scope for research in finding more general models that can harness the power of Transfer learning. (2) There’s scope for a lot of work in using Reinforcement learning for building controls. (3) Some specialized metrics should be created and used that are specific to Transfer Learning.

References
A list of all 77+ references can be found in our review paper that will be published...