Ph.D. Dissertation of Engineering

Implementation of simplified normative dynamic building energy simulator

동적 에너지 시뮬레이션의 단순화 및 규범화 구현

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Abstract

Keyword: Dynamic Simulation, Simplification, Normativization, Spreadsheet, User-Interface

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While dynamic simulation offers higher temporal fidelity and physical realism, its practical use remains limited due to the substantial input requirements, steep learning curve, and dependence on expert judgment. In contrast, steady-state tools have achieved widespread adoption because of their standardized workflows and ease of use. This divergence has created a persistent gap between modeling effort and fidelity in current building energy modeling practice.

To bridge this gap, this research proposes two complementary methods as the foundation for a new dynamic simulators: simplification and normativization. Simplification reduces model dimensionality to the minimum necessary, while normativization introduces validated, reusable presets that replace difficult-to-specify attributes. Together, these strategies aim to retain the temporal and physical rigor of dynamic simulation while reducing the efforts of modeler as typical of steady-state methods.

The thesis defines these methods in detail, formalizing their application to geometry, HVAC systems, and internal loads. It further demonstrates their implementation in a Python-based simulation engine that translates simplified, normative inputs into EnergyPlus-compatible formats. A spreadsheet-based interface is also developed to enhance usability for practitioners. Through these contributions, this work lays the groundwork for a new dynamic simulation tool that can support mainstream adoption.

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

1.1 Research backgrounds

1.1.1 Purpose-driven evolution of building energy simulation tools

Building energy simulation tools have evolved for decades, from manual calculation methods (Cane, 1979; Thom, 1966) to simulation (Crawley et al., 2000; Hittle & Lawrie, 1978) and data-driven methods (Rabl, 1988; Ruch & Claridge, 1992), and recently to large language model based automated methods (Jiang et al., 2024; Liu et al., 2025), along with the development of related fields such as gas laws, heat transfer, thermodynamics (Dienel, 1997; Mao et al., 2013; Stamper, 1994).

This divergence encapsulates the fundamental trade-off between fidelity and accessibility: dynamic tools continually extend the frontier of precision and control, while steady-state tools consolidate practicality, speed, and comparability for mainstream or regulatory applications (Fig. 1.1).

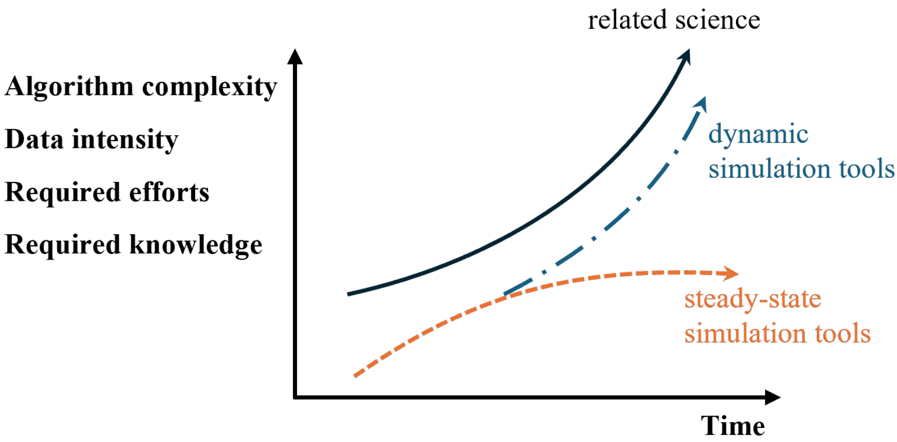


Figure 1.1. Trajectories of dynamic and steady-state simulation tools

Table 1.1. Table Example

Steady-state simulator	**Dynamic simulator**
fast	slow and very slow and hard and slow and hard ans slow and muilti-line
easy	hard

1.1.2 Emerging limits of the steady-state tools under contemporary building trends

As buildings become lower-load and better insulated, integrate renewables and advanced HVAC (e.g., heat pumps with storage), and operate under occupant and policy driven controls, performance depends on temporal coupling among weather, occupancy, and control actions (start-up/shut-down and part-load behavior, short-term storage, and envelope thermal inertia) (Fig. 1.2).

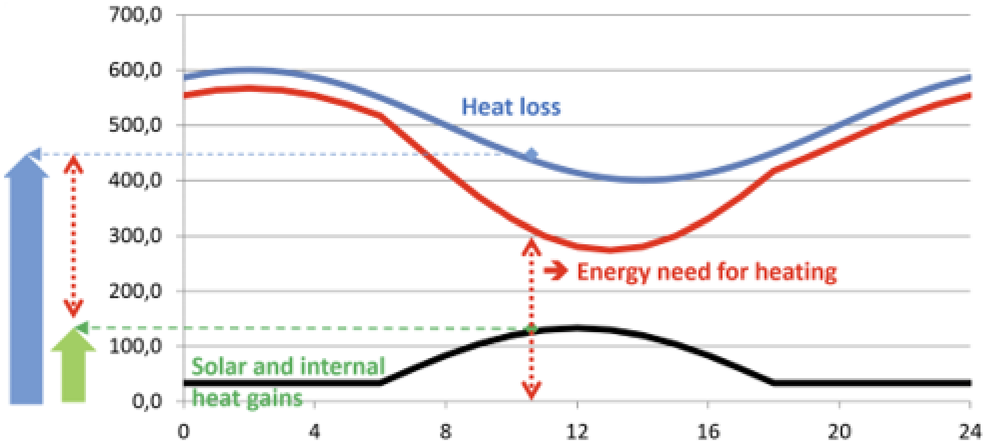
1.1.3 Limitations in widespread adoption of dynamic simulators

Accordingly, the principal impediments are delineated across three foundational input in the sections that follow: domains—geometry, HVAC systems, and internal loads.

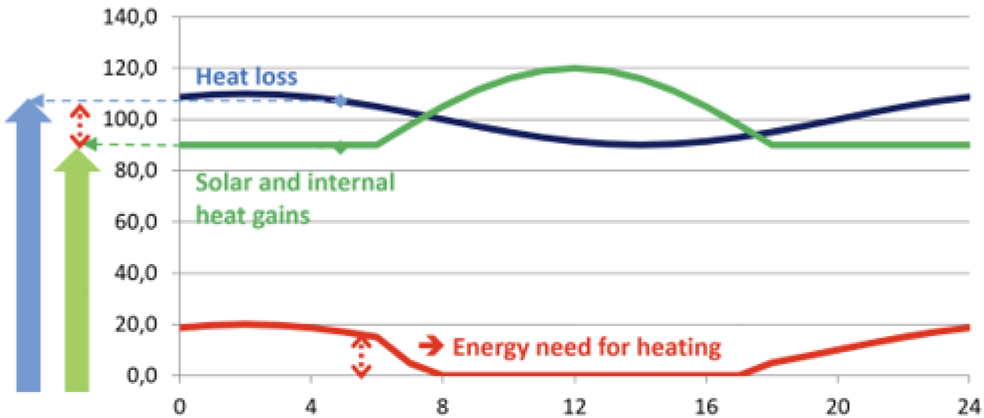
Geometry The result is predictable: rising effort for zone partitioning and boundary conditions, slower iteration, and weakened validation and reproducibility.

HVAC Systems Consequently, QA/QC expands while iteration speed and reproducibility contract.

Internal Loads This combination inflates modeling effort and injects uncertainty that is difficult to audit, eroding credibility and slowing adoption despite the central role of internal loads in performance outcomes.



(a) Past high-energy buildings



(b) Current low-energy buildings

Figure 1.2. Comparison of thermal balances of past and current buildings (van Dijk, 2018)

1.2 Thesis organization

The subsequent chapters are organized as follows:

- **Chapter 2** ...
- **Chapter 3** ...
- **Chapter 4** ...
- **Chapter 5** ...
- **Chapter 6** ...

Chapter 2. Previous efforts to ease use of dynamic simulation tools

2.1 Lightweighted engines

hi

2.2 User-friendly interfaces

clicSAND for OSeMOSYS

2.3 Building templates

Templatized inputs (limited building shapes, ...) for specific building

Urban scale automation??

2.4 Automated modelling approaches

BIM2BEM, LLM

2.5 Issues and limitations of the previous efforts

hi

Chapter 3. Normative simplified building components

3.1 Geometry

3.1.1 Definition of simplified geometry

hi

3.1.2 Simulation of the simplified geometry model in EnergyPlus

hi

3.1.3 Validation for the real-world buildings

hi

3.2 HVAC systems

3.2.1 Definition of simplified HVAC

hi

3.2.2 Definition of normative HVAC

hi

3.3 Internal loads

3.3.1 Definition of simplified profile

hi

3.3.2 Definition of normative profile

hi

Chapter 4. Python-based implementation

4.1 Data hierarchy and conversion procedures

4.1.1 Data hierarchy and classification

hi

4.1.2 Hierarchical conversions

hi

4.2 Building data structure for the simplified normative dynamic simulator

4.2.1 Tree-structured building data

hi

4.2.2 Type of the input variables

hi

4.2.3 Suggested data structure

hi

4.3 Python module structure

4.3.1 Functional module classification

hi

4.3.2 Api for user

hi

4.3.3 Auxiliary modules

hi

4.4 Algorithms for the data conversions

4.4.1 Building data conversion framework

hi

4.4.2 Simplified geometries to idf

hi

4.4.3 Simplified normative HVAC systems to idf

hi

4.4.4 Simplified or normative profiles to idf

hi

Chapter 5. User-Interface

5.1 Spreadsheet based interface

5.1.1 Strength and limitations of the spreadsheet

hi

5.1.2 Spread-sheet based user input

hi

5.1.3 Dedicated launcher for spreadsheet

hi

5.2 Extensiblity for modern framework based interfaces

5.2.1 Strength of the modern frameworks

hi

5.2.2 Example of the React-framework based GUI

hi

Chapter 6. Conclusion

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국문초록

동적 시뮬레이션(dynamic simulation)은 시간적 해상도와 물리적 사실성을 높게 제공하지만, 방대한 입력 요구량, 높은 학습 곡선, 그리고 전문가의 판단에 대한 의존성으로 인해 실제 활용은 여전히 제한적이다. 반면, 정상상태(steady-state) 도구는 표준화된 작업 흐름과 사용의 용이성 덕분에 널리 채택되어 왔다. 이러한 차이는 현재의 건물 에너지 모델링 실무에서 접근성(accessibility) 과 정밀도(fidelity) 사이의 지속적인 간극을 초래하고 있다.

이 연구는 이러한 간극을 해소하기 위해 두 가지 상호보완적 방법, 즉 단순화(simplification) 와 규범화(normativization) 를 새로운 동적 시뮬레이터의 기반 개념으로 제안한다. 단순화는 모델의 차원을 최소한으로 줄이는 것이며, 규범화는 설정하기 어려운 속성을 검증된 재사용 가능한 사전 설정값(preset)으로 대체하는 것이다. 이 두 방법은 동적 시뮬레이션의 시간적 · 물리적 정밀성을 유지하면서도, 정상상태 도구와 유사한 수준으로 모델링자의 작업 부담을 줄이는 것을 목표로 한다.

본 논문은 이러한 두 방법을 건물 형상(geometry), HVAC 시스템, 내부부하(internal loads)에 구체적으로 적용하여 정의하고, 이를 Python 기반 시뮬레이션 엔진으로 구현하였다. 제안된 엔진은 단순화되고 규범화된 입력을 EnergyPlus 호환 형식으로 변환하며, 실무자의 사용 편의성을 높이기 위해 스프레드시트 기반 인터페이스도 함께 개발하였다. 이러한 연구를 통해 본 논문은 실무 적용성을 확보하면서도 분석적 신뢰성을 유지할 수 있는 차세대 동적 시뮬레이션 도구의 기반을 제시한다.

Keyword: 동적 시뮬레이션, 단순화, 규범화, 스프레드시트, UI

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