A Framework for HVAC System Auto-zoning Based on BIM
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Abstract
Zoning is an important step in the design of HVAC (Heating, Ventilation, and Air Conditioning) system, and the results of zoning can affect the operating efficiency of the HVAC system, thus affecting the building’s energy consumption. However, most of this work is currently finished manually based on the designer’s own experience, which is highly subjective and time-consuming for engineers. This paper proposes a new framework for automatic zoning of BIM-based HVAC system design. The framework includes five automatic processes: geometric transformation, thermal zoning, load calculation, system zoning, and system load calculation. In this paper, the zoning process is divided into two stages: thermal zoning and system zoning. Thermal zoning is primarily used during load calculation and energy simulation phases, providing valuable insights for HVAC system design. However, it is important to note that the results of thermal zoning should not be applied blindly, as system design is a more complex process. In addition to load characteristics, factors such as the type of HVAC system, duct layout, and cost considerations need to be taken into account. Furthermore, an office building is used as a case study to demonstrate the automatic load calculation process for the HVAC system.

Highlights
- Clarify the hierarchy of thermal zoning and system zoning in the HVAC system.
- Propose a new HVAC system automatic zoning framework based on BIM.
- Use an office building as the example to validate the feasibility of the automatic load calculation process of the HVAC system.

Introduction
Building Information Modelling (BIM) is a technology that enables the sharing of architectural information among various disciplines which include the design, construction, and operation phases of a building project, facilitating its utilization by all participants involved in the project (Eastman et al., 2008). Therefore, BIM is expected to integrate disparate architectural, engineering, and construction disciplines and optimize the lifecycle performance of buildings (Filzmoser et al., 2016). The utilization of computer technology in the field of building energy analysis has been widely emphasized for a long time (Al-Homoud et al., 2001). Based on the BIM, it is helpful to achieve automatic design of HVAC system (Sha, H et al., 2019). However, in practical engineering, the modelling process is complex and the complete BIM data can be extensive, requiring more manual labour and resources to establish a standardized BIM. Therefore, BIM is predominantly used in areas such as 3D architectural visualization, integrated clash detection of building equipment and pipelines, and building equipment operation and maintenance management. In domains such as HVAC system design, engineers still tend to prefer traditional design processes.

Figure 1: A typical design process for HVAC system.

The typical design process for HVAC system is shown in Figure 1. For each HVAC system design project, designers must perform a lot of tedious work, such as determination of HVAC system and piping layout arrangement. Additionally, due to the continuity of the design process, any modifications to previous steps will affect subsequent design results, which leads to a significant amount of repetitive work (Larsson N et al., 2009).

The HVAC system zoning still have gaps in research, involving processes as indicated by the dashed box in Figure 1. We conducted a questionnaire survey among designers from a design institute, and the results showed that determination of the HVAC system (including system zoning, selection of terminal devices and heating/cooling resources) is one of the difficult parts of HVAC system design.
In the process of HVAC system design, zoning is an important step. Thermal zone is a thermal concept, not a geometric one, which refers to a collection of one or more spaces with similar thermal demands (same temperature and humidity control points). From the perspective of building energy consumption, thermal zones are the most basic thermal units in building energy modelling (BEM). The goal of thermal zoning is to define as few zones as possible that do not significantly affect the accuracy of building simulations. From the perspective of HVAC system design, thermal zones define the independently controlled spatial areas in the building. Reasonable thermal zoning, which aggregates areas with similar functional requirements and thermal characteristics into the same thermal zone, which can be useful in HVAC system design and its operation control, and enables the system to meet the comfort requirements of each room while reducing unnecessary energy consumption.

In the traditional design process of HVAC system, designers often determine thermal zones based on the functions, settings, load characteristics, and geometry information of rooms in the building, combined with their own experience. This method is subjective, and the design results may not necessarily match the actual building situation. Existing automatic thermal zone segmentation algorithms are mostly based on the simplification of BEM, rather than HVAC system zoning principle. With the development of BIM and the popularity of various machine learning (ML) algorithms, segmentation of thermal zones in HVAC system can now be automatically achieved. The building information stored in BIM provides valuable geometry data that serves as the foundation for load calculation. Machine learning algorithms can analyse load data to extract cooling and heating load characteristics of various rooms in the building. This data-driven approach can complement the load characteristics that designers may have overlooked, and make the system zoning results more scientific.

**Related work**

BIM can provide basic data for the entire life cycle of a building (Lin B et al., 2021), improving design efficiency. How to accurately and efficiently obtain relevant information about the HVAC system from BIM has always been a concern. The unification and standardization of two data formats, Industry Foundation Classes (IFC) and Green Building XML (gbXML), have played a crucial role in achieving interoperability between building data and energy simulation tools. These standardized formats have provided a foundation for the development of BIM technology, enabling efficient storage and transmission of BIM data. By promoting the use of these formats, the building industry is able to advance environmentally-friendly and sustainable practices, contributing to the overall growth and progress of the sector (Prada-Hernandez et al., 2015). Compared with IFC, which aims to adopt comprehensive and universal methods to represent the entire building project, gbXML is mainly developed to facilitate data conversion from BIM to engineering analysis tools (especially BEM tools). This is because the gbXML format files can recognize information such as the geometric shape of buildings, building components and their adjacency relationships, building location (geographic coordinates and orientation), and thermal zones (rooms and spaces) (Gao et al., 2019). A workflow has been developed to generate lightweight geometry documents in the gbXML format, allowing for the extraction of geometric and related information from BIM models (Yang et al., 2019). This workflow addresses the challenge of inconsistencies in building information stored between BIM and BEM tools, to some extent. By utilizing gbXML, it becomes feasible to perform HVAC system load calculations and ensure more accurate results. This process helps bridge the gap between BIM and BEM, enhancing the coordination and integration of building information for improving energy analysis and design decision-making.

There have been a number of academic and commercial software developed both domestically and abroad that aim to improve the interoperability between BIM and BEM. BIM-based building energy simulation software includes various tools, such as Autodesk’s Ecotect Analysis and Insight software, Green Building Studio's energy cloud computing service for Revit, the IES VE software developed by the British company IES, and Rhino, among others. This calculation software mainly uses the standards of the foreign countries, and BIM for domestic buildings cannot be fully automated for simulation and calculation. The application of BIM technology in China started later than that in foreign countries. PKPM-Energy, developed by the China Academy of Building Research, can also import Revit models for load and energy consumption calculation. However, the software's load calculation method is relatively simple and mainly considers the HVAC system load caused by the building envelope’s heat transfer and solar radiation. It can be used for equipment selection calculations and energy consumption evaluations during the design stage, but the accuracy of energy consumption simulation and control during the operation stage is obviously insufficient. The HY-EP software developed by Hongye Technology can provide dynamic load and energy consumption calculations for the entire year, but it still needs to manually set the room properties and zoning information, and the simulation speed for large models is slow. If the model needs to be simplified to reduce calculation time, it still requires manual changes to the model.

Hongxin Wang et al. proposed a conceptual framework of HVAC system automated design process based on artificial intelligence technology, aimed to optimize or replace rule-based traditional HVAC system design process and effectively solve the problem of time lag between HVAC system and building design and structural design (Wang et al., 2022). However, the algorithm proposed in the paper is mainly developed for office buildings and the robustness of the algorithm still needs to be improved. In the research of building zoning, Aurelien Bres et al. conducted a study on building performance simulation (BPS) and obtained different simulation zones by considering different spatial
properties and using multiple zoning schemes to analyse simulation results, but the study mainly focused on residential buildings and heating systems (Bres et al., 2018).

Research gaps
Currently, there is a substantial amount of research on BIM and BIM-based BEM processes. Through literature reviews and the study of relevant software tools, there are three innovative research gaps that need to be addressed:

1. There is a lack of semantic interoperability between BIM and BEM tools, leading to inconsistencies between the building information stored in BIM and BEM. This requires a certain degree of data conversion in the BIM-based BEM process (Gao et al., 2018). In actual engineering, the BIM modelling process usually involves multiple disciplines, and the complete BIM data is large. The detailed and high-level building information in BIM is too complex for BEM. For example, the rooms or spaces in BIM do not always represent the thermal zones in BEM. Additionally, some important building information in BEM, such as boundary conditions, may be missing in BIM.

2. Irregular BIM modelling can result in incomplete geometric topology space, which can affect the establishment of BEM and even lead to calculation interruption.

3. HVAC system requires consideration of system zoning, including the determination of load characteristics, smoke control system design, type of HVAC system and so on. This part is still usually done manually, which makes HVAC system design time-consuming, labour-intensive, and subject to human experience, increasing the inexplicability of HVAC system design.

To fill the research gaps mentioned above, this paper proposes a new BIM-based HVAC system zoning framework. First, the BIM is processed for lightweight, and the key information of the BEM is extracted, supplemented, repaired and checked to achieve automated geometric reconstruction. Then, automatic thermal zoning is carried out based on factors such as room function and orientation. Building’s hourly cooling and heating load throughout the year is calculated using load calculation software to obtain key parameters for HVAC system design. Finally, the system is divided based on the user-defined system segmentation rules or through a multi-objective optimization process, and the results of system zoning will serve as the basis for HVAC system selection and design. The automatic zoning framework will reduce the workload of the designers to a certain extent, avoid work errors or technical mistakes, and improve design quality.

Methodology
The paper focuses on the research of automatic zoning algorithm for buildings. The technical approach of the framework can be divided into five processes: automatic geometry transformation, automatic thermal zoning, zone load calculation, automatic system zoning, and system load calculation, as shown in Figure 2.

![Figure 2: A Framework for HVAC system auto-zoning based on BIM.](https://doi.org/10.26868/25222708.2023.1714)

In the field of HVAC, thermal zoning and system zoning are two different concepts that are interconnected yet have distinct roles in design and operation of HVAC systems. Thermal zoning primarily serves as a reference for HVAC system design during load calculation and energy simulation stages. However, it should not be solely relied upon without considering additional complexities involved in system design. Factors such as load characteristics, system configuration, piping layout, cost, and more should also be taken into account. While proper thermal zoning establishes a foundation for system zoning, adjustments and optimizations in system zoning should be made based on the specific requirements and characteristics of thermal zones. Coordinated design and operation of thermal zoning and system zoning are crucial in achieving occupant comfort, building energy efficiency, and sustainability.

Thermal zoning refers to the process of dividing the interior of a building into different zones based on cooling and heating load and indoor comfort requirements. The purpose of thermal zoning is to partition different areas within a building according to their unique thermal characteristics, functional usage or comfort requirements, in order to facilitate better temperature control, heating, and cooling. Typically, thermal zoning takes into account factors such as building layout, insulation performance, orientation of external walls, internal heat loads and more. System zoning, on the other hand, involves dividing the HVAC system into different zones based on functional and control requirements. A building may consist of multiple system zones, where each zone corresponds to an independent HVAC system or control area. System zoning is typically based on factors such as the type of HVAC system, range of supply for heating and cooling sources, control strategies, load characteristics, operating schedules, room functions, physical locations, fire and explosion protection, and other considerations.

Therefore, the algorithm for automatic zoning is divided into two phases: the pre-processing phase of load calculation based on building geometry information,
spatial layout, and room function, which aims to reduce the complexity of load calculation and improve the speed of it while ensuring the rationality of spatial processing; and the post-processing phase of building load calculation based on the results of building load calculation and the building spatial layout, which combines the thermal characteristics, cooling and heating load characteristics, smoke exhaust system design, and other properties of each room in building to generate the system zoning results of HVAC system.

**Automatic geometric transformation**

The reason for using BIM as input in this workflow framework is that BIM could provide valid data that are required for energy simulation, which means that users usually do not need to recreate this information for BEM. This is based on the concept of BIM-based BEM, which makes generating BEM more efficient. Currently, research on BIM-based BEM can be divided into four groups, namely IFC-based methods, gbXML-based methods, BIM-based Modelica BEM methods, and other BEM developments based on BIM (Gao et al., 2018).

However, due to the lack of semantic interoperability between BIM and BEM, the process of geometry transformation is particularly important and relatively complex. Spatial information can be provided by BIM, but the materials of the envelope, properties of windows, as well as the schedule information in BEM, usually come from the external database. The information required for BEM with a good quality and its data sources are listed in the Table 1.

**Table 1: The information required for a good quality BEM and its data sources.**

<table>
<thead>
<tr>
<th>Information category</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial information</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>BIM</td>
</tr>
<tr>
<td>Building</td>
<td>BIM</td>
</tr>
<tr>
<td>Space</td>
<td>BIM</td>
</tr>
<tr>
<td>Surface</td>
<td>BIM</td>
</tr>
<tr>
<td>Climate</td>
<td>database</td>
</tr>
<tr>
<td>Construction</td>
<td>BIM or database</td>
</tr>
<tr>
<td>Layer</td>
<td>BIM or database</td>
</tr>
<tr>
<td>Materials</td>
<td>BIM or database</td>
</tr>
<tr>
<td>Window type</td>
<td>BIM or database</td>
</tr>
<tr>
<td>Schedule</td>
<td>BIM or database</td>
</tr>
</tbody>
</table>

**Automatic thermal zoning**

Thermal zoning aims to simplify the calculation nodes of BEM, that is, zoning reduction. Simplifying some airflow nodes of the models that do not need to be considered in energy analysis during building load calculation can greatly improve the speed of model calculation. Simultaneously, merging thermal zones to create fewer indoor air nodes can greatly reduce computational complexity and enhance iteration efficiency, all within an acceptable error tolerance. However, blindly merging thermal zones often leads to errors. For instance, it is essential to consider scenarios where temperature stratification and uneven airflow distribution are prone to occur in high and spacious environments, particularly when dealing with large room areas and considerable room depths. And there are significant differences in load between interior and exterior areas. Therefore, it is necessary to add heat transfer surfaces at appropriate locations.

Taking all factors into account, as shown in Figure 3, this paper proposes an automatic thermal zoning algorithm for the building-level zoning stage, which is the pre-processing stage of zone load calculation, including the split process 1 and 2 for tall and large spaces and internal and external partitioned room; the merge process 1 and 2 for small spaces and rooms with the same orientation and function. After applying these algorithms, a modified BEM will be generated.

A simple strategy for appropriate zone segmentation is to define an outer boundary zone, at least according to the sunlit area load as specified in ASHRAE 90.1 Appendix G, for rooms that are too large or have high connectivity. This will establish an outer zone with a depth of 15 ft, which more accurately represents the local load of the space and prevents underestimation of energy consumption (Wang et al., 2022).

**Figure 3: An automatic thermal zoning algorithm for the building-level zoning stage.**

The algorithms involved in the split process mainly include:

1. **Clump splitting algorithm** is used to roughly split polygons with an area exceeding the threshold by using the clustering technique. The bottleneck positions of automatically identified graphics are weakened to reduce the topological connectivity of a single thermal zone.

2. **Straight skeleton algorithm** is used to uniformly retreat the external walls to form complex curve regions. The retreat is based on the outer boundary of the planar graphics. The straight skeleton algorithm iteratively processes four types of events, including inner zone fractures, edge disappearance, triangle merging, and retreat collision until the retreat distance meets the set value, generally 15ft.

3. **Hertel-Mehlhorn algorithm** is used to decompose the polygon into convex shapes. This step is not necessary but is performed to match the load calculation engine's radiation calculation mode. Because for the energy model itself, the triangulation method usually introduces a large number of unnecessary fragmented faces, which slows down the radiation calculation speed.
The merging algorithm is based on conditions such as the number of floors, function, space area, and orientation of the rooms. During the merging process, all heat transfer surfaces at the interfaces of the thermal zones are replaced with heat storage surfaces.

The algorithm offers several advantages. For instance, in cases where the building area is extensive, there can be a notable disparity in cooling and heating load between the external rooms or areas around the building and the internal rooms or areas. To ensure convenient control and adjustment of indoor parameters, it becomes necessary to consider both the internal and external areas when dividing the system. This process framework takes this aspect into account during automatic thermal zoning prior to zone load calculation.

**Zone load calculation**

Zone load in this framework is the result of an annual energy analysis of the building's HVAC system based on hourly weather data for 8760 hours. It serves as the data source and basis to ensure the accurate design results. Common building hourly load calculation or energy consumption simulation software includes EnergyPlus, eQUEST, DesignBuilder, etc. Figure 4 shows the corresponding input file format of the energy simulation software.

![Figure 4: The corresponding input file format of the energy simulation software.](image)

Each software has its own characteristics and functions, and the selection of software needs to be evaluated and chosen based on specific circumstances. Currently, the most widely used approach is the BIM-based BEM process based on EnergyPlus.

**Automatic system zoning**

Traditional HVAC system zoning is based on room load characteristics, occupancy time, room function and location, temperature and humidity parameters, fire prevention design, etc. Its rules are highly subjective and because there is no detailed hourly load analysis for each room, the actual load characteristics of the rooms may differ significantly from expectations.

This framework utilizes the annual load calculation results of each room and extracts the hourly load characteristics based on the clustering method in Step 1. In addition, based on the geometric locations of each room in Step 2, rooms with similar spatial locations are grouped into the same system to avoid subjective biases from designers. The flowchart of the automatic system zoning process is shown in Figure 5.

![Figure 5: A Framework for automatic system zoning process.](image)

In Step 1, the load clustering method used in this algorithm is k-means clustering, which has the characteristics of fast convergence and strong interpretability. In k-means clustering, the Calinski-Harabasz (CH) criterion is used to determine the optimal number of clusters. This criterion measures the compactness and separation of clusters by the ratio of intra-cluster and inter-cluster distances, and a larger CH index is usually used to indicate higher clustering quality. The clustering results and the corresponding HVAC system zoning results are different for different values of the clustering parameter k.

The actual value of k in the design process is related to the setting form of HVAC system, which involves building-level and system-level automatic zoning algorithm in Step 2. For different types of HVAC system, the design conditions of the rooms are different, and the requirements for the similarity of loads are different, that is, the requirements for the similarity of the enthalpy ratio of the rooms are different. The corresponding relationship between the type of HVAC system and the principles of system zoning are shown in Table 2.

<table>
<thead>
<tr>
<th>HVAC system category</th>
<th>Rule-based and cluster results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable air volume system (VAV)</td>
<td>Zoning based on load characteristics and geometric proximity</td>
</tr>
<tr>
<td>Constant air volume system (CAV)</td>
<td>Zoning based on load characteristics and geometric proximity</td>
</tr>
<tr>
<td>Fan coil unit (FCU) with fresh air system</td>
<td>Fresh air system is zoned based on the characteristics of the fresh air load and geometric proximity; Fan coil water system only has one zone for the whole floor</td>
</tr>
<tr>
<td>Variable refrigerant volume system (VRV)</td>
<td>Zoning based on load characteristics and geometric proximity</td>
</tr>
<tr>
<td>Radiant terminal system</td>
<td>Fresh air system is zoned based on the characteristics of the fresh air load and geometric proximity; Coil water system only has one zone for the whole floor</td>
</tr>
</tbody>
</table>
Combined air conditioning system | Zoning based on load characteristics and geometric proximity within each system

**System load calculation**

After the above process, according to Step 2 shown in the Figure 5, the calculation framework can select the result with the least number of zones according to the user-specified HVAC system format as the basis for subsequent HVAC system equipment selection, and generate a corresponding list of rooms for system zoning.

**Case Study**

An office building with a total of 5 floors is taken as an example to verify the feasibility and robustness of this framework. The selection of the office building as the validation framework for the algorithm is based on several factors. This decision is made due to the presence of diverse functional areas within the office building, including large spaces like standard floors. This setup offers an excellent opportunity to validate the accuracy of the algorithm during the thermal zoning phase. Furthermore, the outcomes of load clustering provide valuable insights to evaluate the effectiveness of the system zoning approach.

The total area of this building is 10,125 m², and the air-conditioned area is 6,149 m². The height of the first floor is 9 m, and the height of the second to fifth floors is 4.5 m. This building is located in Shanghai, China. The air-conditioned rooms on the first floor are hall and lecture room, and the air-conditioned rooms on the second to fifth floors are offices, the second floor is the standard floor.

Based on the automatic load calculation framework proposed in this paper, the BIM is used as the input for load calculation, as shown in Figure 6. After preprocessing of BIM, the gbXML file with lightweight model was obtained, which is visualized as shown in Figure 7. After geometric transformation, BEM can be obtained, and then automatic zoning algorithm for building hierarchy is used to split and merge the planar space. Since the office room on the standard floor of the building have large areas and deep room depths, interior and exterior zoning is required.

According to the algorithm, the exterior walls of the building were offset 5 m inward for room zoning, and rooms with the same function and orientation were merged. The final building-level auto thermal zoning result is shown in the Figure 8 below. The office has been divided into office_n facing north, office_s facing south, office_w facing west, office_e facing east, and the centric area office_c located in the middle.

EnergyPlus was selected for load calculation, and after automatic thermal zoning, the modified BEM generated is an IDF format file suitable for EnergyPlus calculation. The above process can shorten the load calculation time while improving the reliability of the load calculation results.

Further clustering was performed on the load results, and the clustering results were visualized as a dendrogram as shown in Figure 9. The selected HVAC system for this building is a VAV system. VAV systems can adjust the supply air volume according to the actual requirements to match the varying load in different zones of a building. Compared to CAV systems, VAV systems can more precisely control air flow and temperature, avoiding unnecessary energy waste and achieving energy-saving effects. Afterwards, the automatic zoning algorithm at the system level was used to obtain the load calculation results of the HVAC system, as shown in Table 3, which is convenient for subsequent equipment selection and other operations.

**Figure 8: Automatic thermal zoning result of standard floor.**

**Figure 9: Load clustering result of standard floor.**

**Figure 10: Traditional zoning result of standard floor.**
When applying the traditional HVAC design method without any zoning for the office rooms, as shown in Figure 10, the load calculation results for the standard floor are presented in Table 3. Upon comparing the results, it becomes evident that the load calculation result without thermal zoning and system zoning is 139.4 kW, which is nearly identical to the result of 136.5 kW obtained after zoning based on the framework. The error is only 2%, further validating the rationality of this algorithm in thermal zoning. However, the load results obtained through the traditional HVAC design method only consider the total load of the rooms. This can subsequently necessitate recalculation of the load results for the internal and external zones during system design, thereby increasing the complexity of the design process. If these load results are not recalculated and uniformly distributed, it can lead to an unreasonable design, consequently impacting the comfort experience of occupants.

The final result of the system zoning using this algorithmic framework is to cluster the areas or rooms facing south and east into one HVAC subsystem, and those facing north and west into another HVAC subsystem, which meets the design requirements and further verifies the feasibility and scientific of this new automatic zoning framework. It is evident that although the BEM can directly calculate the load of each room, the utilization of the proposed auto-zoning framework in this paper can optimize the load results. This framework generates HVAC system solutions that are more interpretable and provides effective data support for subsequent equipment selection.

Table 3: The load calculation results of the HVAC system after system zoning.

<table>
<thead>
<tr>
<th>Level</th>
<th>Room function</th>
<th>Area (m²)</th>
<th>E+ cooling load index (W/m²)</th>
<th>System Zoning Load (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>hall</td>
<td>1158</td>
<td>110</td>
<td>127.4</td>
</tr>
<tr>
<td></td>
<td>lecture</td>
<td>276</td>
<td>134</td>
<td>37</td>
</tr>
<tr>
<td>Level 2</td>
<td>office c &amp; e &amp; office w</td>
<td>1113</td>
<td>84</td>
<td>93.6</td>
</tr>
<tr>
<td>(with system zoning)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>office s</td>
<td>380</td>
<td>112.8</td>
<td>42.9</td>
</tr>
<tr>
<td>Level 2</td>
<td>office</td>
<td>1493</td>
<td>91</td>
<td>139.4</td>
</tr>
<tr>
<td>(without system zoning)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

This paper proposes a new BIM-based HVAC system load calculation framework that is more robust and applicable to a wider range of scenarios. Compared with traditional HVAC design that requires a lot of manual labor and resources, the automatic load calculation framework proposed in this paper can automate the model reconstruction work of designers in the building energy consumption analysis process. This paper focuses on researching the five automatic process including automatic geometry transformation, automatic thermal zoning, zone load calculation, automatic system zoning, and system load calculation. The conclusions are drawn as follows:

1. This framework divides zoning into two parts, building-level and system-level, which can simplify the model and improve the speed of load calculation, while also achieving efficient and reasonable design of HVAC systems.
2. This framework achieves automated model reconstruction in the lightweight processing of BIM and extracting, supplementing, repairing, and checking key information in BEM.
3. This framework automatically divides the thermal zones based on factors such as room function and orientation. This primarily aims to reduce the computational complexity of the load calculation engine and improve its speed while simultaneously ensuring the accuracy of the calculations.
4. This framework utilizes load calculation software to calculate the hourly cooling and heating load of the building for entire year, obtaining key parameters for selection and calculation of the building’s HVAC system, and providing effective data support for subsequent algorithms.
5. Based on the user-defined system zoning rules or multi-objective optimization process, this framework completes the zoning of HVAC system, and the results of system zoning will serve as the basis for system selection and design. This will reduce workload of frontline designers to some extent, avoid work errors or technical mistakes, and improve design quality.

This study also has limitations:

1. The pre-processing part of the BIM in the proposed framework still relies on a good quality model, and the poor quality of the model is likely to lead to the failure of the geometric information transformation, thus the robustness of the algorithm in this part still needs to be improved.
2. The correspondence between HVAC system types and zoning principles can be combined with the latest design standards, and rule-based principles can be extracted using NLP (Natural Language Processing) techniques.
3. During the building design stage, the building load calculation model is a white-box model that is too ideal and may not cover errors introduced during construction and operation.
4. There are still gaps in research on load distribution in atriums.

The author will continue to improve the BIM-based HVAC system load calculation framework with the aim of increasing its robustness.
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