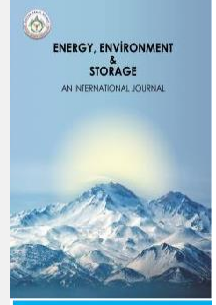




Energy, Environment and Storage

Journal Homepage: www.enenstrg.com



Comparison of Cooling Loads of a Building in the Site with Heat Balance and Radiation Time Series Methods and Computer Aided Analysis

Mehmet Çolak¹, Yasin Kaya^{2*}, Sebahattin Ünalın³,

¹Erciyes University, Faculty of Engineering, Department of Mechanical Engineering, Kayseri, Turkey

mehmetcolak58@hotmail.com ORCID: 0009-0005-2895-5081

²Erciyes University, Faculty of Engineering, Department of Mechanical Engineering, Kayseri, Turkey

yasin-3858@hotmail.com ORCID: 0009-0006-6054-2786

³Erciyes University, Faculty of Engineering, Department of Mechanical Engineering, Kayseri, Turkey

s-unalan@erciyes.edu.tr ORCID: 0000-0002-5605-2614

ABSTRACT. Recently, extensive research has been conducted on energy saving in the buildings. Cooling loads and heat gains stand out as a pivotal factor influencing energy consumption, underscoring the critical need for accurate calculations. This study aims to compare Radiation Time Series and Heat Balance methods, recognized as optimal approaches for cooling load calculations in the ASHRAE Handbook, utilizing computer software. The primary focus of this investigation was a four-floor U-type geometry primary school in Kayseri, comprising 116 space and 93 zones. The building was modeled using Revit software, employing Radiant Time Series method, and IESVE software, incorporating Heat Balance method. All relevant data inputs were defined, and subsequent cooling load calculations were executed. The outcomes reveal with Revit producing a total cooling load estimate 0.6% lower than IESVE. In conclusion, the values derived from both RTS and HB methods for calculating the building's cooling loads exhibit noteworthy proximity, affirming the robustness of these methodologies in conjunction with computer software applications.

Keywords: Cooling Loads, RTS, HB, Revit, IESVE

Article History: Received: 05.01.2024; Accepted: 18.01.2024;

Doi: <https://doi.org/10.52924/PODW1839>

1. INTRODUCTION

E. Mushtaha et. al. simulated a building with using IESVE, inputting parameters such as shading devices, ventilation and building materials to reduce the cooling load requirement [1]. S. Dagher et. al. analyzed a school building in Minneapolis using IESVE software for energy and daylighting analysis [2]. M. H. Elnabawi investigated the comparison of Revit (Building Information Modeling) with Designbuilder-IESVE (Building Energy Modeling). The problems encountered while importing the project Revit to Designbuilder and IESVE and some improvements suggested that needed to be made working in these software [3]. Kaya Y. modeled U-type building by Revit and researched cooling loads trends for different orientation of building [4]. As can be seen in the studies, it is important to use software that calculates cooling loads such as Revit (Radiant Time Series method) and IESVE (Heat Balance method).

The first and most significant factor for designing an air conditioning system to function accurately throughout the

year is to have precise heating and cooling load calculations. This ensures the determination of correct device capacities at the design stage. When calculating heating loads, peak time is equal to coldest ambient temperature time. However, calculating cooling loads is more complex and challenging than calculating heating loads. Because cooling peak time can vary greatly depending on the number of people in the place, devices, lightings and most of all the position of the sun. To address this complexity, it is crucial to choose the most accurate calculation method and leverage computer software support. The cooling load calculation methods in the ASHRAE Handbook, several approaches was found suitable: TETD/TAM (Total Equivalent Temperature Difference Time Averaging Method), CLTD/SCL/CLF (Cooling Load Temperature Difference Solar Cooling Load-Cooling Load Factor), TFM (Transfer Function Method), RTS (Radiant Time Series) and HB (Heat Balance). HB method, which is called the exact solution and is the basis of the cooling load calculation methods proposed to date, is complex and requires the use of computers[5].

Software applications like IESVE and Carrier HAP v6 employ HB method, while Revit, using RTS method, can calculate loads [6]. Fig. 1 provides information about the accuracy and complexity of load calculation methods, considering the softwares utilizing these methods [7].

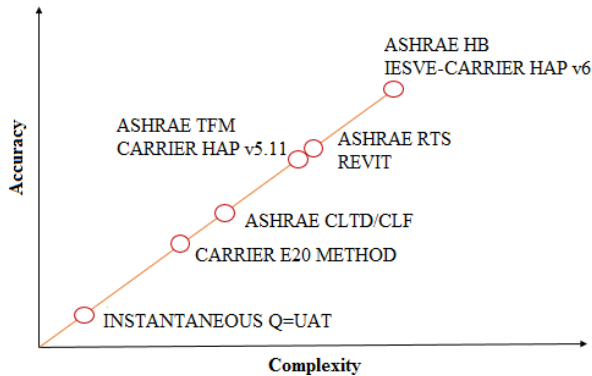


Fig. 1. Accuracy and Complexity for Load Calculations for Different Softwares

In this study, the architectural project of a primary school building in Kayseri was created using Revit. Subsequently, the required designs and data inputs were specified in Revit MEP. Following this, the school building, along with the surrounding high-rise buildings and local shading devices, was modeled using IESVE, with the same data inputs defined in IESVE. Fig. 2 depicts the location and photographs of the school [8].



Fig. 2. Primary School Photographs



2. MATERIALS AND METHODS

2.1 Radiant Time Series Methodology

RTS is a simplified method for calculating cooling load which is derived from HB method. As such, the use of RTS is more important than the use of all other simplified methods (TFM, CLTD/CLF method and TETD/TA method) [5]. The advantages of using this method which is the general procedure for calculating the cooling load of each load component (lights, people, walls, roofs, windows, appliances, etc.) with RTS is as follows:

- A 24-hour profile of component heat gains is calculated for the design day (for conduction; firstly conduction time delay is considered by applying conduction time series).
- Heat gains are split into two forms, the radiation and convection parts.
- Appropriate radiation time series are applied to the radiation part of the heat gains to account for the time delay in conversion to cooling load.
- The convection portion of the heat gain and the delayed radiative portion of the heat gain are added to determine the cooling load of each component for each hour.

After calculating the cooling loads of each component for each hour, these components are summed to determine the total cooling load and the hour of peak load is determined for the design of the air conditioning system. This process is repeated over multiple design months to determine the month in which the highest load occurs [6]. Fig. 3 illustrates RTS methodology.

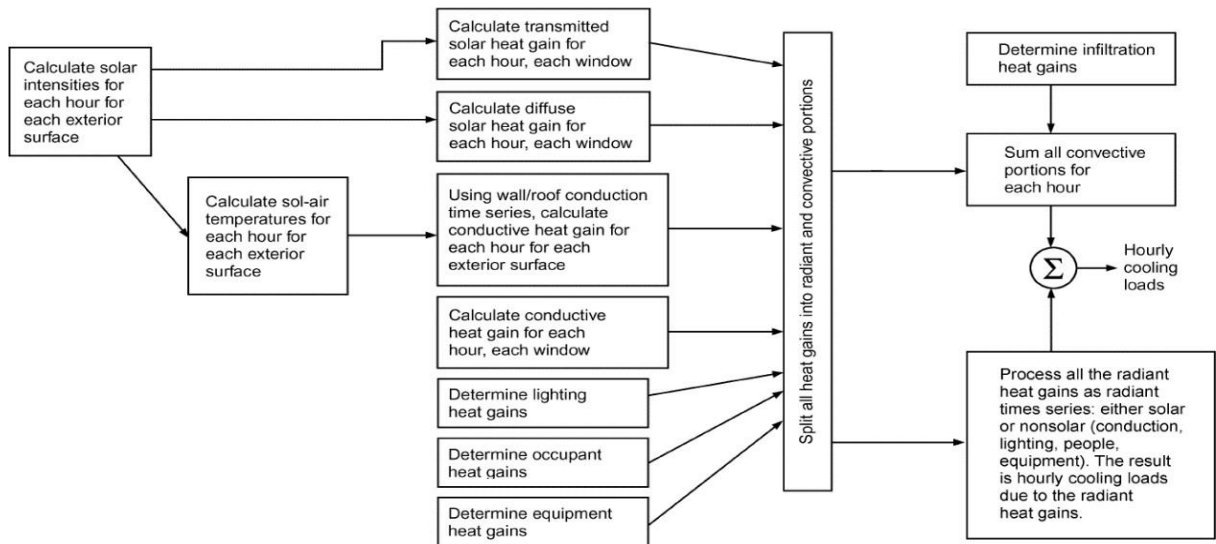


Fig. 3. Radiant Time Series Methodology

2.2 Modeling by Revit

Shapes, structures and systems in 3D and generated plans, elevations, schedules, sections, and sheets can be modelled by Revit. Afterwards, Building Information Modeling (BIM) can be created and modeled for the purpose of designing mechanical or electrical system design. Cooling and heating loads can be calculated in a BIM process. Revit uses RTS method for these calculations. And also, Revit can analyze the energy performance of buildings [9].

3D photographs and floor plans of the school modeling by Revit are shown in Fig. 4, 5, 6, 7, 8. Within the building, there are indoor areas with many different functions such as classroom, library, gym, school canteen, corridor, office enclosed, infirmary, storage, restrooms. 116 spaces and 96 zones were created according to the areas of use in the building. Input datas defined for the characteristics of these spaces and zones. The same process was done on IESVE.



Fig. 4. Primary School 3D Photographs on Revit

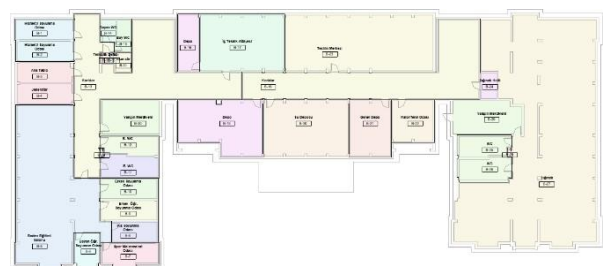


Fig. 5. Basement Floor

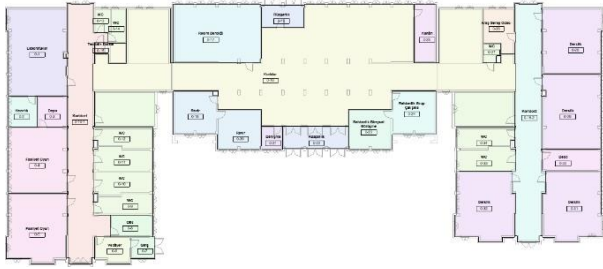


Fig. 6. Ground Floor

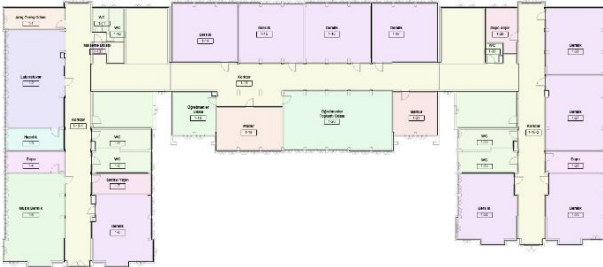


Fig. 7. First Floor



Fig. 8. Second Floor

2.3 Heat Balance Methodology

Cooling load determination involves calculating a surface-to-surface conduction, convection, and radiative heat balance for each room surface and a convection heat balance for the room air. The HB method, which forms the basis of cooling load calculations, solves the problem directly rather than applying conversion based procedures. The advantages of this method is containing no arbitrarily set parameters and does not eliminate any operations [5].

The HB Method calculates time delay effects explicitly with some basic assumptions like uniform surface temperatures. Conductive, convective, and radiative heat balance are calculated directly for each surface within a room [10]. Heat Balance method has four distinct processes:

- Outdoor face heat balance
- Wall conduction process
- Indoor face heat balance
- Air heat balance

A process detailed in the accompanying Fig. 9 clearly illustrate the relationships for a sample opaque surface. The processes duplicated for each surface covering the whole zone. Similarly, this can be applied for transparent surfaces. However, absorbed solar energy by the building components conducts the heat inside and a portion of solar incident is not reflected back to the sky and transmitted to inside. These heat gain or losses affect the surface heat balances. [5].

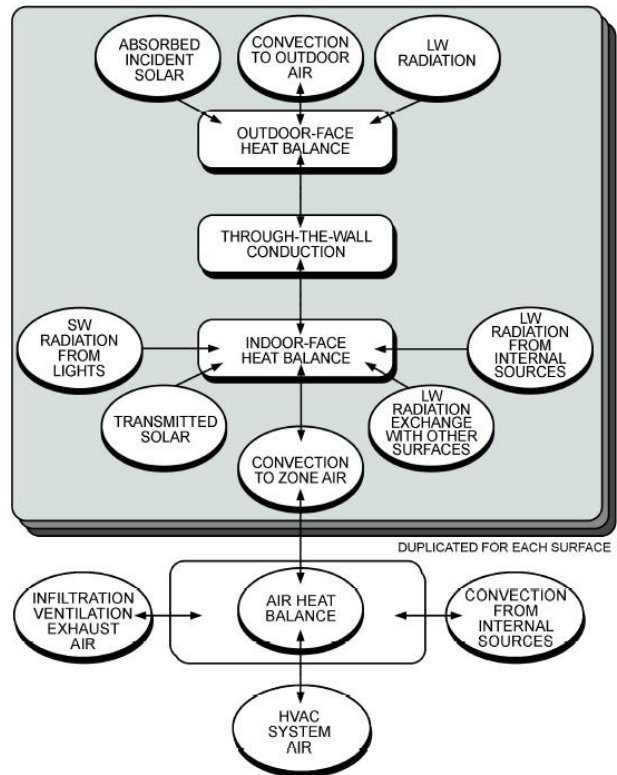


Fig. 9. Heat Balance Methodology

The ASHRAE Heat Balance Method states that the “sum of all space instantaneous heat gains at any given time does not necessarily (or even frequently) equal the cooling load for the space at that same time”. Fig. 10 attempts to convey this phenomenon by demonstrating the time delay associated with the ‘Gains vs Loads’ discussion [6].

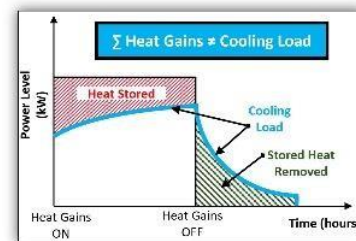


Fig. 10. Thermal Storage Effect in Cooling Load From Internal Gains

2.4 Modeling by IESVE

IESVE is a Building Energy Modeling (BEM) Software that perform calculations for industry standard heating and cooling loads including options for the ASHRAE Heat Balance method or CIBSE Admittance method with IESVE. IESVE assesses daylight metrics for LEED & BREEAM such as Spatial Daylight Autonomy (sDA) and Useful Daylight Illuminance (UDI). It performs minimum ventilation calculations, evaluates outdoor air supply from mechanical HVAC systems or natural ventilation design. Furthermore, it uses Computational Fluid Dynamics (CFD) airflow simulation to evaluate occupant comfort and overheating potential. In addition to this it can evaluate predictive metrics for site energy, source energy, energy cost and carbon emissions by using the world-renowned APACHE simulation engine [11].

3D photographs and floor plans of the school modeling by IESVE are shown in Fig. 11, 12, 13, 14, 15. The drawings

that appear green colors show the shading elements that cause local shading, and the drawings that appear pink colors show the shading of adjacent buildings. Since the shading effect cannot be calculated with drawing on Revit, the shading effect was not included in the calculations on IESVE for comparison of methods.

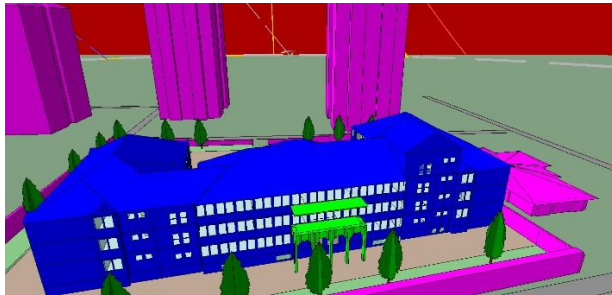
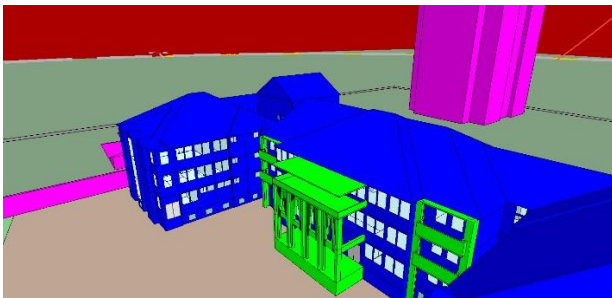
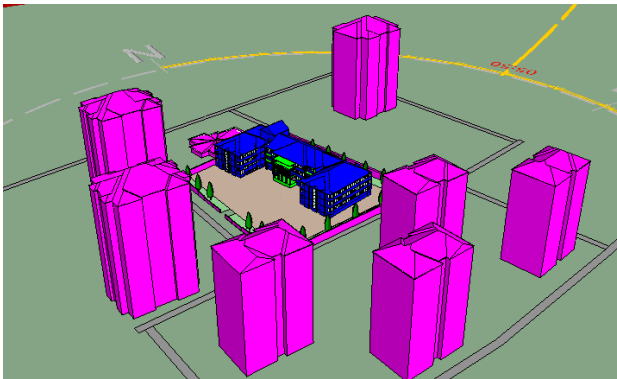


Fig. 11. Primary School 3D Photographs on IESVE

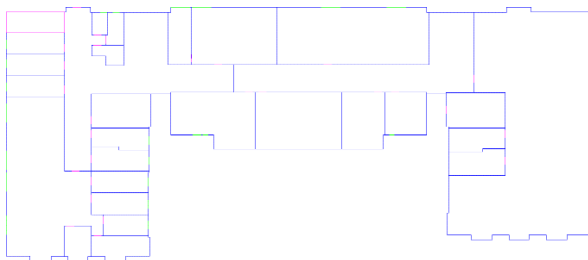


Fig. 12. Basement Floor

Fig. 13. Ground Floor

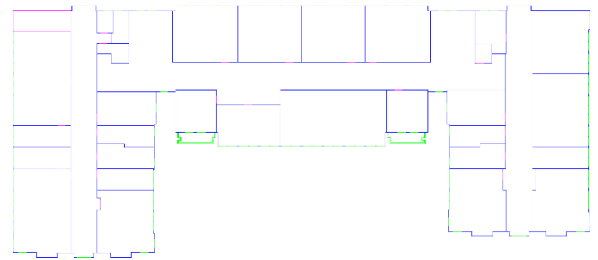


Fig. 14. First Floor

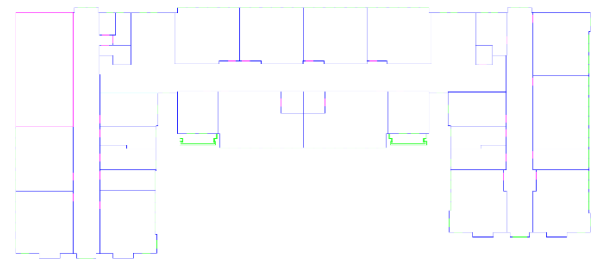
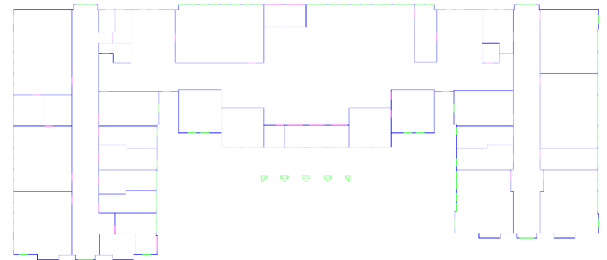


Fig. 15. Second Floor

2.5 Data Inputs

Accuracy of calculations and results is of great importance comparing two calculation methods. For this reason, separate modeled were created for both software. Revit's drawing technique, wall thicknesses can drawn, but IESVE, only line drawings can drawn. This causes small deviations in internal areas. However, because heat gains are low on the wall, this is negligible. Many data inputs need to be defined on both Revit and IESVE. In order to compare 2 software and 2 different calculation methods, all data inputs defined same in softwares which were shown Tables 1 and 2. Kayseri city chose for design weather data on Revit and IESVE.

Table 1 Parameters and Data Inputs

| Parameters | Data Inputs |
|--------------------------|---|
| Space Types | Classroom-Library-Gym-School Canteen-Corridor-Office Enclosed Infirmary-Storage-Restrooms |
| Number of People | Numbers specific to each space were entered |
| Lighting and Power Loads | Space specific option selected and these values entered. |
| Occupable Schedules | 8 AM to 6 PM |
| Lighting Schedules | 4 PM to 6 PM |
| Cooling Set Point | 23 °C |
| Cooling Air Temperature | 12 °C |

Table 2 Construction Types

| Construction | U (Overall Heat Transfer Coefficient W/m ² .K) | SHGC (Solar Heat Gain Coefficient) |
|------------------|---|------------------------------------|
| Exterior Walls | 0,8108 | |
| Interior Walls | 1,4773 | |
| Floors | 1,361 | |
| Slabs | 0,7059 | |
| Doors | 3,7021 | |
| Exterior Windows | 1,9873 | 0,39 |
| Roof | 0,6819 | |

3. RESULTS AND FIGURES

Through the analysis, it was ascertained that Revit and IESVE produced total cooling load estimates of 411.11 kW and 413.64 kW, respectively, resulting in a discrepancy of merely 0.6%. A detailed breakdown of the cooling loads for individual floors, as assessed by both Revit and IESVE, is illustrated in Fig. 16. A visual examination of these graphics reveals a noteworthy consistency, with cooling load values in nearly all zones exhibiting close proximity to each other.

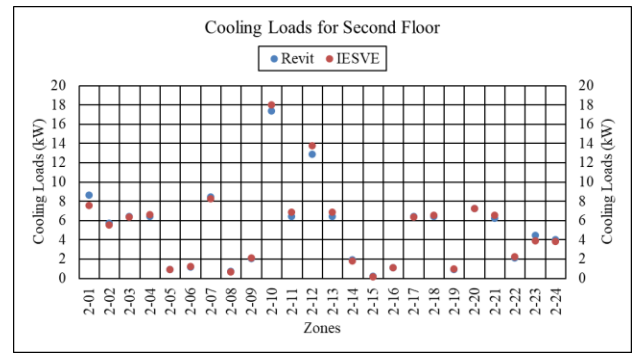


Fig. 16. Comparison of Cooling Loads of Each Floor by both Revit and IESVE

When calculating the cooling loads by Revit, if the building is exposed to shading, it cannot calculate the effect of shading on the cooling load. On the contrary, cooling loads with and without the shading effect were calculated by IESVE. In addition, it is not possible to select the calculation date range when cooling loads are calculated by Revit, but date range can be selected on IESVE. In other words, if desired, the results can be further optimized by selecting date ranges which cooling loads are important.

In this study, RTS and HB methods were compared by Revit and IESVE and shading effect neglected. Apart from this study, both shading effect and June-August date range selected on IESVE and building was simulated again. As a result of the calculations, the total cooling load was 389.8 kW. In other words, self-shading, local shading, and shading of adjacent buildings reduced the total cooling load of the building by 5.8%.

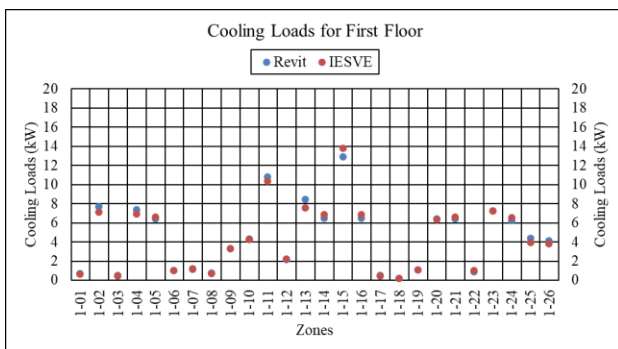
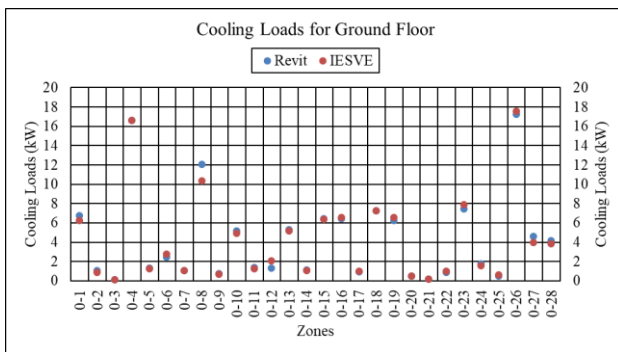
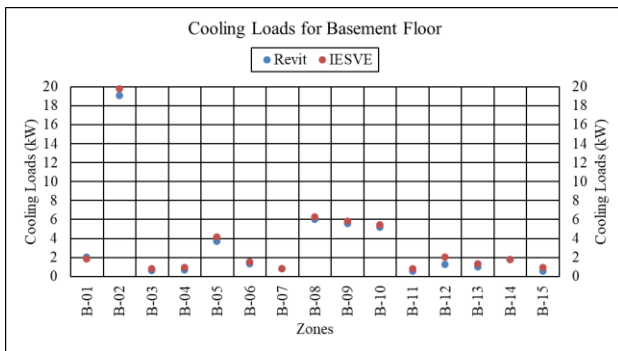
4. CONCLUSION

In previous studies with by using Revit and RTS:

Laxi et. al. were calculated cooling loads of a hotel building by two methods, RTS method by Revit and CLTD/CLF/SCL method, compared cooling loads are closely approximate each other by acceptable range of 10% [12]. Matej modeled a referential building, calculated cooling loads with Revit and then compared Revit to Energie 2015 software in terms of energy performans [13]. Nabin was created a residential building by Revit and calculated heating and cooling loads with RTS method [14]. Vittoria et. al. was modeled The Maritime Station of Naples by Revit and DesignBuilder softwares to compare cooling loads. Cooling peak loads was calculated 3,333 ve 3,055 kW respectively [15].

In previous studies with by using IESVE and HB:

Zohaib et. al. were generated Dynamic Thermal Simulation by IESVE which models residential spaces. The energy consumption reduced by 8% and cooling loads by 20% by using Variable Speed Drive instead of using fan coil [16]. Baskara et. al. studied Geometrical model which is a student dormitory. Seven stories was created by IESVE. Heat gains were comperad to ventilation, solar, lighting, people, equipment. They figured out that the most heat gain parameter was lighthting [17]. Sigalingging et. al. were modeled the building (6mx10mx2.85) plan and then it has been simulated by IESVE with the Passivhaus standard. It was calculated 11.41 MWh for original layout, 10.89 MWh for the house with Passivhaus application in terms of annual



cooling energy use [18]. Budiyo et al. were selected a refrigerated container for estimated of energy consumption based on the cooling loads. Research was conducted in two stage, firstly the measurement data were obtained from the experimentation, later container was modeled by IESVE. Energy consumption was compared with IESVE result and measurement data. Both study results were found to be compatible with each other [19].

Numerous methodologies and software applications are employed for the computation of cooling loads, with RTS and HB methods recognized as the most precise albeit intricate. Within the scope of this investigation, a comparative analysis was undertaken between the RTS and HB methods, revealing no substantial disparities in the resulting calculations.

Regarding the software employed, Revit stands out for its capacity to generate detailed architectural projects. Its notable feature lies in employing the RTS method for the calculation of cooling loads. However, it is worth noting that Revit lacks the capability to factor in the effects of shading on cooling loads within its drawings. Conversely, IESVE serves as a thermal analysis calculation software, offering the distinct advantage of calculating shading effects on cooling loads, coupled with its utilization of the HB method.

REFERENCES

- [1] E. Mushtaha, T.Salameh, S. Kharrufa, T. Mori, A. Aldawoud, R. Hamad ve T. Nemer, The impact of passive design strategies on cooling loads of buildings in temperate climate, 2021, Case Studies in Thermal Engineering, Volume 28.
- [2] S. Dagher, B. Akhozheya ve H. Slimani, Energy analysis studying the effect of solar shading on daylight factors and cooling hours in an extreme weather, 2022, Energy Reports, Volume 8: 443-448.
- [3] M. H. Elnabawi, Building information modeling-based building energy modeling: Investigation of interoperability and simulation results, 2020, Frontiers in Built Environment, Volume 6.
- [4] Kaya Y., 2020. Numerical investigation of the effect of buildings location plans on the cooling load, Erciyes University, Master Thesis, Kayseri.
- [5] Ashrae Handbook Committee, 2021. Nonresidential cooling and heating load calculations, pp. 18.17-18.25, ASHRAE Handbook-Fundamentals, Atlanta.
- [6] Web pages:
<https://www.iesve.com/discoveries/article/10017/ashrae-heating-and-cooling-load-calculations>
<https://www.carrier.com/carrier/en/worldwide/news/news-article/carrier-releases-hap-v6--a-major-upgrade-to-hvac-system-design-software.html>
<https://help.autodesk.com/view/RVT/2020/ENU/?guid=GUID-D88E8A06-6E08-4CD6-89A0-368A2AD6C03C>
 (Dated access: January 2024).
- [7] Yıldız A., Ersöz M.A., Altınar A., Bilki T.B., Computer aided analysis of cooling load calculations, 12th national plumbing engineering congress, İzmir, 2015, MMO.
- [8] Web page:
<https://parselorgu.tkgm.gov.tr/#ara/cografı/38.789566937045954/35.61383485794068>
 (Dated access: January 2024).
- [9] Web page:
<https://www.autodesk.com/solutions/revit-vs-autocad>
 (Dated access: January 2024).
- [10] Web page:
<https://www.iesve.com/discoveries/blog/3348/ashrae-heat-balance-method-radiant-time-series-whats-the-difference>
 (Dated access: January 2024).
- [11] Web page:
<https://www.iesve.com/software/virtual-environment>
 (Dated access: January 2024).
- [12] Laxmi G., R L. S., Bim-Based energy performance modeling and simulation of hotel building, 2023, Journal of Data Acquisition and Processing, Volume 38: 237-255.
- [13] B. Matej K., 2018. Implementation of BIM systems for energy analysis and optimization in buildings, Czech Technical University In Prague, Master Thesis, Prague.
- [14] Nabin T., 2020. Enhancement of HVAC load, energy consumption and energy cost for a proposed residential building, Thesis, Nepal.
- [15] Vittoria B., Alberto C., Alessandro M., Gennaro N., On the interoperability of building information modeling for energy analysis: the case study of the Maritime Station of Napoli (Italy), IOP Conference Series: Earth and Environmental Science, 2022.
- [16] Zohaib S. , Hassam N. C., Energy modelling and indoor air quality analysis of cooling systems for buildings in hot climates, 2018, Fluids.
- [17] S. A. Baskara, G. S. Adi, S. S. Utami, B. Prayitno, and FX P. J. Guntoro, Cooling load analysis in asrama kinanti 1 ugm using building performance simulation, 2020, IOP Conference Series: Earth and Environmental Science, Volume 520, Indonesia.
- [18] R. C. Sigalingging, D. Chow and S. Sharples, Modelling the impact of ground temperature and ground insulation on cooling energy use in a tropical house constructed to the Passivhaus Standard, 2019, IOP Conference Series: Earth and Environmental Science, Volume 329, Cardiff, Wales.
- [19] M. A. Budiyo, Nasruddin, F. Zhafari, Simulation study using building-design energy analysis to estimate energy consumption of refrigerated container, 2019, Energy Procedia, Energy Procedia, Volume 156: 207-211.