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Comparative study of numerical and algebraic approaches for the evaluation of the thermal balance of a sports hall Located in Italy

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Abstract: The global energy landscape is characterized by an ever-increasing demand for energy driven by population growth, urbanization, and technological advancements, while concurrently facing the challenge of reducing greenhouse gas emissions and minimizing carbon footprints. In this context, energy-efficient buildings have emerged as a pivotal solution, accounting for approximately 40% of global energy consumption *[1]*. This study focuses on the energy design of a school building in Italy, aligning with stringent energy efficiency standards to create an environmentall²y friendly and user-comfortable educational facility.

The research integrates key aspects of energy engineering, including the sizing of hydraulic and air distribution networks, thermal analysis, ventilation, and heating systems. A comparative approach was employed, combining manual calculations and advanced numerical simulations to evaluate various design solutions. The primary objective of this study was to assess the thermal performance of the building under different scenarios, optimizing energy consumption while maintaining indoor comfort.

The results highlight the potential of simulation-based energy design to enhance decision-making in sustainable building projects. By comparing thermal balances under diverse conditions, the study provides insights into the optimal configurations for heating, ventilation, and air conditioning (HVAC) systems. These findings contribute to advancing energy-efficient practices in building design and underscore the importance of adopting an integrated, simulation-driven approach to achieve sustainable construction objectives.

Keywords: Energy simulation, Thermal balance, Energy efficiency, Sustainable building, HVAC systems

Nomenclature :

T : Temperature [K]

S : Surface [m^2]

Φ : heat flow [W]

e: Thickness [m]

R : Thermal resistance[m^2.K/W].

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λ : thermal conductivity [W.m.K]

K : heat transfer coefficient [**W/m².K**]

I. INTRODUCTION

This work deals with a specific part of a study on the energy design of a school building located in Castiglione delle Stiviere, Italy;

More specifically, it calculates the gymnasium's heat balance using two distinct approaches: A traditional method based on theoretical calculations, and a second method based on the use of specialized software tools.

The first software to be used is **Edilclima** [2], a tool dedicated to evaluate the energy performance of buildings. Designed to meet Italian legal and regulatory requirements, Edilclima can be used to produce energy performance certificates (CPE), check compliance with applicable regulations and carry out energy audits. The software is particularly well-suited to the Italian regulatory and climatic context, offering a complete and accurate solution for projects located in this region.

The second tool used is Revit, a building information modeling (BIM) software package developed by Autodesk; Designed for the creation of technical drawings and architectural designs, it also offers advanced functionalities for building energy simulation. Unlike Edilclima, Revit adapts to a wide variety of climatic contexts and international projects, making it a versatile tool for architects and engineers. Its integrated tools enable energy performance to be assessed during the design phase, providing opportunities for energy optimization and informed decision-making.

This study aims to compare these two approaches by evaluating their efficiency and limitations in conducting the thermal balance of a building. By comparing the results obtained through the traditional method and numerical simulations, we aim to demonstrate the advantages and disadvantages of each method, as well as their relevance in different contexts. This analysis will contribute to a better understanding of the tools available for the eco-responsible design of modern buildings.

II. CALCULATION OF THE HEAT BALANCE

A. Heat balance calculation using standard equations applied to HVAC systems *[3]*

Outside temperatures	Winter- 8°C ; H.R. 80%
	Summer + 35°C ; H.R. 50%
Building category:	E.6(2): Buildings used for sporting activities: gymnasiums and similar E.7: Buildings used for school activities at all levels and similar

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Fig 1:3D view of the gym

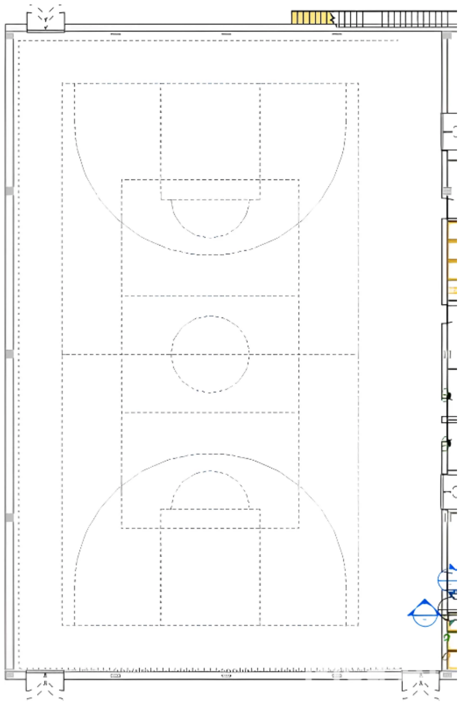

Fig 2:2D view of the gym

TABLE I
SIZE OF THE SPORTS HALL

Length	34 m²
Width	22.5 m²
Height	8 m²
Area 1	180 m²
Area 2	272 m²
Floor and ceiling	765 m²

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2)Calculation of thermal transmittance : Here we use the standart equations

- *composition of external walls*

TABLE 2
SURFACE THERMAL RESISTANCE

External surface thermal resistance R_{se}	0.13m²K/W
Internal surface thermal resistance R_{si}	0.073m²K/W

TABLE 3:
DIFFERENT LAYERS OF THE OUTER WALL

Material	**e (cm)**	**λ (W/m.K)**	**R (m².K/W)**
Double-sheet plasterboard,	1.25	0.25	0,05
Vapour barrier, tarpaulin	0.1	0.33	0,00303
Rock wool - Extra white paint	7.5	0.034	2,205882
Perforated block	40	0.143	2,797203
Lime and sand render - White	2.5	0.8	0,03125
Double-sheet plasterboard	1.25	0.25	0,05
Heat transfer coefficient K (W/m2.K)			0,187

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$$K = \frac{1}{0,05 + 0,003 + 2,2 + 2,8 + 0,03 + 0,05 + 0.13 + 0.073}$$

$$K = 0.187 \text{ W/m}^2\text{.K}$$

Using the same method and an Excel spreadsheet, we can determine the other thermal transmittance coefficients

➢ *Calculating wall losses*

Remarks	**Envelope**	**K (W/m².K)**	**S (m²)**	**T (K)**	**Φ (W)**
Sunny walls	Wall 1	0,187	180	10	336,6
	Wall 2	0,187	180	10	336,6
	Wall 3	0,187	272	10	508,64
Wall in contact with an unconditioned room	Wall 4	0,212	60,8	7	90,56
Top unconditioned	Ceiling	0,16	765	22	2692,8
In contact with the ground	Floor	0,173	765	5	664,53
4 Windows	Windows	1,093	15,18	10	663,67
three French windows	French windows	1,3	3,87	10	150,93
Total					**5444,33**

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2) Thermal bridges : Thermal bridges account for around 15% of total losses or 816W

3) Air renewal losses : The occupancy rate of the gym is 0.125 people/m².

i.e. approximately 89 people with a usable surface area of 712 m².

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- <u>Heat Sensitive</u>

QSen = qv . (θe-θ i) . 0,34

Qsen = 7565 W

- <u>Latent heat</u>

$$\mathbf{QLat = qv\,.\,(\omega e - \omega i)\,.\,0{,}84}$$

Qlat = 15170.4 W

Q air renewal =15170.4+7565

Q air renewal =22735,4W

4) Solar heat gain : It is an important part

- <u>On the walls</u>

$$Q\text{sunny walls} = \alpha\,.\,F\,.\,S\,.\,Rm$$

Q sunny walls = 1170 W

- <u>On French windows</u>

Q sunny French windows = α . g . S . Rv

Q sunny French windows = 166W

- <u>On the windows</u>

Q windows = α . g . S . Rv

Q Window = 730W

Q solar gain= Q Window + Q sunny French windows

Q solar gain = 2066W

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5) Heat input from occupants : The project recommends 64W/person for sensitive loads and 46W/person for latent loads.

- Sensitive loads
  $$\mathbf{QSensitive = n\,.\,CSensitive}$$

Q sensitive input= 5696 W

- Deferred contributions

QLatent = n . CLatent

Q latent contribution =3956

Q latent contribution = Qlatent + Qsensitive

Q occupant contribution = 9652W

6) Electrical heat input : It is load of Lighting and Electrical equipment

Q electric = $\sum Qequipement$

Q electric = 14240 W

TABLE 4 :
HEAT BALANCE CALCULATION RESULTS SPORTS HALL

Thermal loads	**[w]**
Envelope losses	5444,334
Thermal bridges	816,650
air renewal	22735,4
solar gain	2066
Occupant contributions	9652
Electrical inputs	14240
Total	54954,38

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B-Heat balance with Edilclima *[2]*

1)Basic data entry : This section allows the entry of climatic data according to the location of the building; it also allows the selection of the calculation standard to be used and default data such as air exchange, occupancy density, thermal load per person and per equipment.

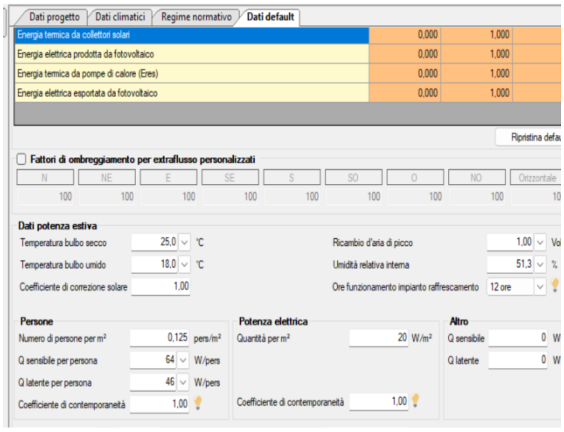

Fig 3 Default project data

2) Material characteristics input : In this section, we enter the material components of walls, roofs, floors and windows, and model thermal bridges.

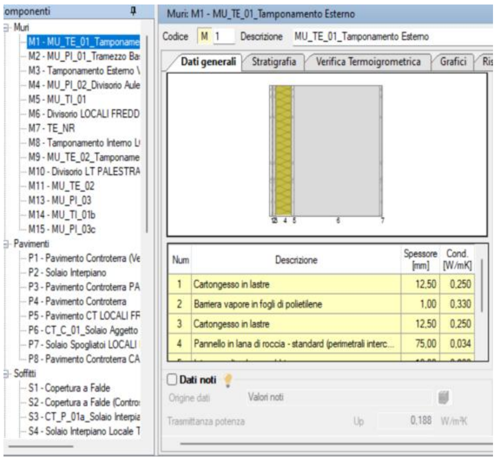

Fig 4:Wall layers

3) Room data : Once the building is modeled, the characteristics of each room have to been entred, if it has data other than the basic data.

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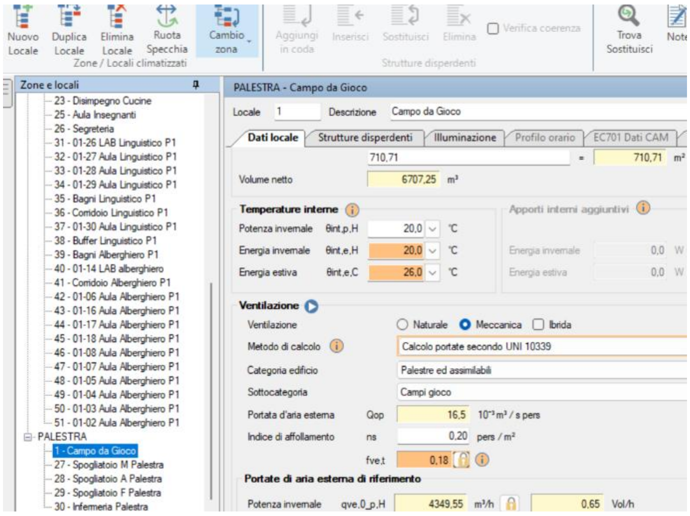
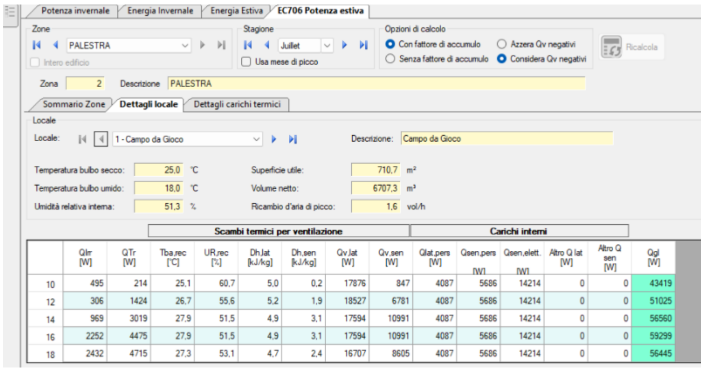


Fig 5 Gym data on EDILCLIMA

4) Energy simulation : Once all this data has been entered, the energy simulation can be carried out, with detailed results for each room and for the whole building.



	Qlrr [W]	QTr [W]	Tba,rec [°C]	UR,rec [%]	Dh,lat [kJ/kg]	Dh,sen [kJ/kg]	Qv,lat [W]	Qv,sen [W]	Qlat,pers [W]	Qsen,pers [W]	Qsen,elett. [W]	Altro Q lat [W]	Altro Q sen [W]	Qgl [W]
10	495	214	25,1	60,7	5,0	0,2	17876	847	4087	5686	14214	0	0	43419
12	306	1424	26,7	55,6	5,2	1,9	18527	6781	4087	5686	14214	0	0	51025
14	969	3019	27,9	51,5	4,9	3,1	17594	10991	4087	5686	14214	0	0	56560
16	2252	4475	27,9	51,5	4,9	3,1	17594	10991	4087	5686	14214	0	0	59299
18	2432	4715	27,3	53,1	4,7	2,4	16707	8605	4087	5686	14214	0	0	56445

Fig 6 Edilclima result of the gym

Referring to Edilclima results, the Thermal peak load is 59299W

C-Energy simulation with Revit software [4]

1) Modelling architectural elements: The first step is to ensure that the architectural elements have the same technical specifications as the specifications (conductivity, thickness, etc.).

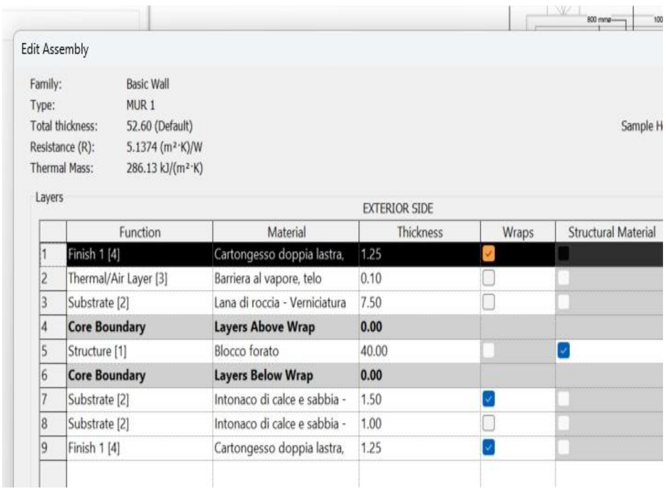


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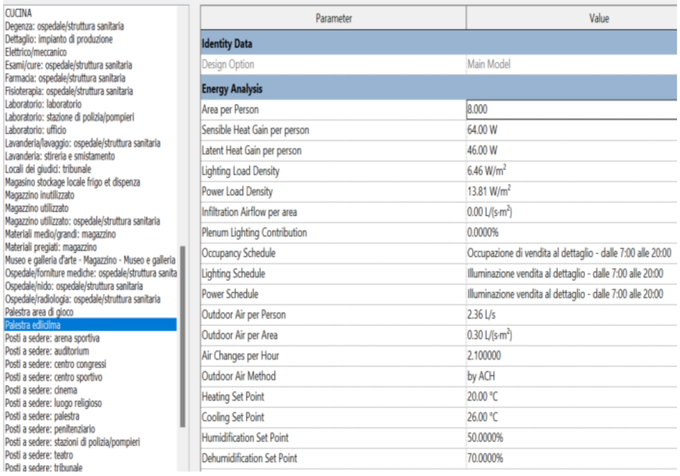
Fig 7 wall properties

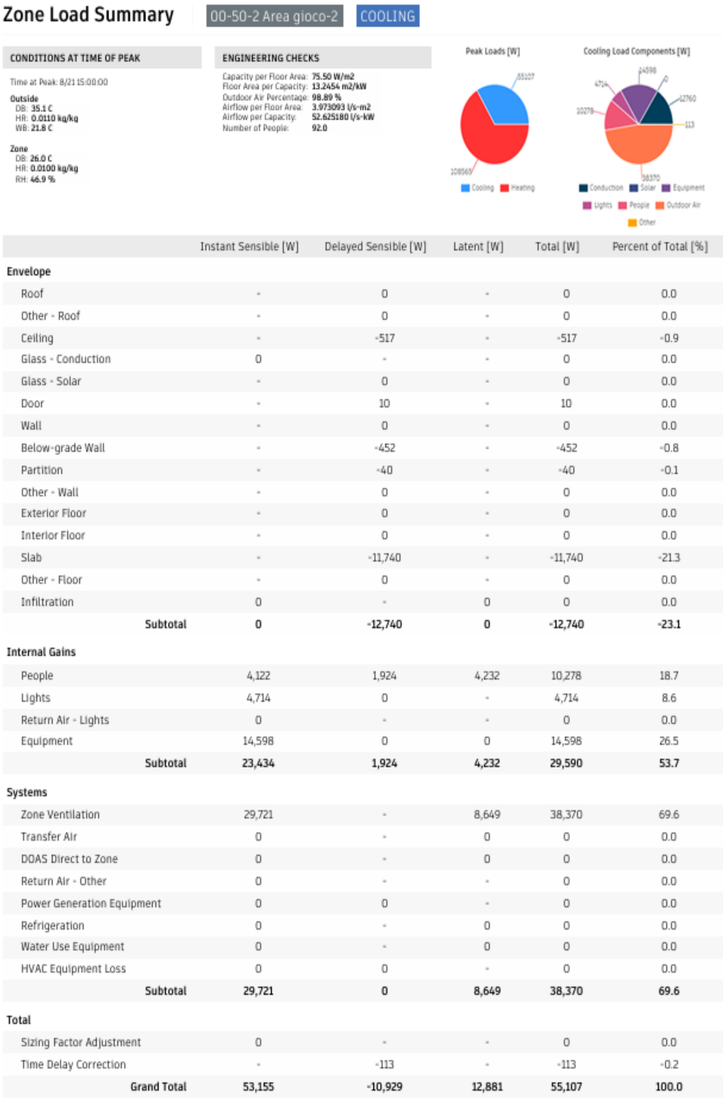
1) *Space data :* After faithfully reproducing the dimensions of the sports hall on Revit, we move on to the entrance to the hall's technical facilities. At this point we need to create spaces in Revit and give these different spaces their own characteristics


CUCINA
Degenza: ospedale/struttura sanitaria
Dettaglio: impianto di produzione
Elettrico/meccanico
Esami/cure: ospedale/struttura sanitaria
Farmacia: ospedale/struttura sanitaria
Fisioterapia: ospedale/struttura sanitaria
Laboratorio: laboratorio
Laboratorio: stazione di polizia/pompieri
Laboratorio: ufficio
Lavanderia/lavaggio: ospedale/struttura sanitaria
Lavanderia: stireria e smistamento
Locali dei giudici: tribunale
Magasino stockage locale frigo et dispenza
Magazzino inutilizzato
Magazzino utilizzato
Magazzino utilizzato: ospedale/struttura sanitaria
Materiali medio/grandi: magazzino
Materiali pregiati: magazzino
Museo e galleria d'arte - Magazzino - Museo e galleria
Ospedale/forniture mediche: ospedale/struttura sanita
Ospedale/nido: ospedale/struttura sanitaria
Ospedale/radiologia: ospedale/struttura sanitaria
Palestra area di gioco
Palestra edilcilma
Posti a sedere: arena sportiva
Posti a sedere: auditorium
Posti a sedere: centro congressi
Posti a sedere: centro sportivo
Posti a sedere: cinema
Posti a sedere: luogo religioso
Posti a sedere: palestra
Posti a sedere: penitenziario
Posti a sedere: stazioni di polizia/pompieri
Posti a sedere: teatro
Posti a sedere: tribunale

Parameter	Value
Identity Data	
Design Option	Main Model
Energy Analysis	
Area per Person	8.000
Sensible Heat Gain per person	64.00 W
Latent Heat Gain per person	46.00 W
Lighting Load Density	6.46 W/m²
Power Load Density	13.81 W/m²
Infiltration Airflow per area	0.00 L/(s·m²)
Plenum Lighting Contribution	0.0000%
Occupancy Schedule	Occupazione di vendita al dettaglio - dalle 7:00 alle 20:00
Lighting Schedule	Illuminazione vendita al dettaglio - dalle 7:00 alle 20:00
Power Schedule	Illuminazione vendita al dettaglio - dalle 7:00 alle 20:00
Outdoor Air per Person	2.36 L/s
Outdoor Air per Area	0.30 L/(s·m²)
Air Changes per Hour	2.100000
Outdoor Air Method	by ACH
Heating Set Point	20.00 °C
Cooling Set Point	26.00 °C
Humidification Set Point	50.0000%
Dehumidification Set Point	70.0000%

Fig 8 Characteristics of the gym

2) *Results of gym simulation:* On the follow image


Zone Load Summary 00-50-2 Area gioco-2 COOLING

CONDITIONS AT TIME OF PEAK
Time at Peak: 8/21 15:00:00
Outside
DB: 35.1 C
HR: 0.0110 kg/kg
WB: 21.8 C
Zone
DB: 26.0 C
HR: 0.0100 kg/kg
RH: 46.9 %

ENGINEERING CHECKS
Capacity per Floor Area: 75.50 W/m2
Floor Area per Capacity: 13.2454 m2/kW
Outdoor Air Percentage: 98.89 %
Airflow per Floor Area: 3.973093 l/s-m2
Airflow per Capacity: 52.625180 l/s-kW
Number of People: 92.0

	Instant Sensible [W]	Delayed Sensible [W]	Latent [W]	Total [W]	Percent of Total [%]
Envelope					
Roof	-	0	-	0	0.0
Other - Roof	-	0	-	0	0.0
Ceiling	-	-517	-	-517	-0.9
Glass - Conduction	0	-	-	0	0.0
Glass - Solar	-	0	-	0	0.0
Door	-	10	-	10	0.0
Wall	-	0	-	0	0.0
Below-grade Wall	-	-452	-	-452	-0.8
Partition	-	-40	-	-40	-0.1
Other - Wall	-	0	-	0	0.0
Exterior Floor	-	0	-	0	0.0
Interior Floor	-	0	-	0	0.0
Slab	-	-11,740	-	-11,740	-21.3
Other - Floor	-	0	-	0	0.0
Infiltration	0	-	0	0	0.0
Subtotal	**0**	**-12,740**	**0**	**-12,740**	**-23.1**
Internal Gains					
People	4,122	1,924	4,232	10,278	18.7
Lights	4,714	0	-	4,714	8.6
Return Air - Lights	0	-	-	0	0.0
Equipment	14,598	0	0	14,598	26.5
Subtotal	**23,434**	**1,924**	**4,232**	**29,590**	**53.7**
Systems					
Zone Ventilation	29,721	-	8,649	38,370	69.6
Transfer Air	0	-	0	0	0.0
DOAS Direct to Zone	0	-	0	0	0.0
Return Air - Other	0	-	-	0	0.0
Power Generation Equipment	0	0	-	0	0.0
Refrigeration	0	-	0	0	0.0
Water Use Equipment	0	-	0	0	0.0
HVAC Equipment Loss	0	0	-	0	0.0
Subtotal	**29,721**	**0**	**8,649**	**38,370**	**69.6**
Total					
Sizing Factor Adjustment	0	-	-	0	0.0
Time Delay Correction	-	-113	-	-113	-0.2
Grand Total	**53,155**	**-10,929**	**12,881**	**55,107**	**100.0**

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Fig 9 Revit result

III. VALIDATION OF THEORETICAL/SIMULATION RESULTS

According to the 3 methods adopted, results of the Thermal peak load are as follows

Table 5
Energy balance for the gym

Manual energy balance calculation	54955 W
Energy simulation with EDILCLIMA	59299W
Energy simulation with REVIT	55107W

- EDILCLIMA compared with REVIT

$$\frac{59299-54955}{59299}*100 = 7.3\%$$

- Comparison between EDILCLIMA and manual calculation

$$\frac{59299-55107}{59299}*100 = 7.1\%$$

- Comparison of REVIT and manual calculation

$$\frac{55107-54955}{55107}*100 = 0.27\%$$

The results of the Revit and manual simulations are very Close. The Edilclima result is slightly higher by 7%.

IV. INTERPRETATIONS

Comparison of the simulation results between Revit, manual calculations and Edilclima software shows that the results obtained with Revit and manual calculation methods are very close, while those obtained with Edilclima are slightly higher by 7%. This difference can be explained by several technical reasons linked to the specificities and methodologies of the software.

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- *Accuracy of local standards and regulations*:

Edilclima is a specialized software for the Italian market, and is designed to comply rigorously with Italian energy standards. Italian regulations may require higher safety margins or more detailed calculation methods, which can lead to more conservative results. This means that parameters such as heat transfer coefficients, thermal bridge correction factors, or safety coefficients can be adjusted more strictly in Edilclima.

- *Calculation Methodology and Simulation Assumptions*:

Energy simulation software, such as Edilclima, uses methodologies that can include additional correction factors and more specific calculation parameters that are not taken into account in basic manual calculations or in Revit. For example, Edilclima can take into account local micro-climatology, the thermal inertia of materials, or specific ventilation and infiltration scenarios, which can lead to slightly higher results.

- *Modeling and Data Granularity*:

The granularity of modeling data in Edilclima can be finer than in Revit. This means that Edilclima can model more details in a building's structure, such as insulation layers, interfaces between different materials, and glazing types. A more detailed model often results in a more accurate and sometimes higher estimate of energy consumption, by incorporating elements that manual calculations or tools like Revit might simplify or ignore.

- *Simulation scenarios and usage profiles*:

Edilclima can offer more advanced simulation capabilities that take into account more varied usage scenarios and more specific occupancy profiles. For example, it could model finer variations in lighting, heating or air-conditioning usage according to time of day or season, which could also lead to higher energy consumption results.

In summary, the slight 7% increase in Edilclima results compared to Revit or manual calculations can be attributed to a combination of factors, including the rigor of local standards, the complexity of calculation assumptions, the granularity of modeling data, and the sophistication of simulation scenarios. These elements enable Edilclima to provide a more specific and potentially more accurate energy assessment for buildings in Italy.

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