Optimizing Energy Efficiency in Zone 4 (Ifrane) Using TRNSYS Simulations

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Abstract. This study investigates the thermal behavior of a building in Zone 4 (Ifrane) using TRNSYS, focusing on the impact of envelope parameters on energy consumption. Different insulating materials (wood wool, glass wool, expanded polystyrene, and wood fiber) and insulation thicknesses were evaluated to reduce heat losses and enhance thermal comfort. Simulations show that both the type of material and its thickness significantly affect thermal performance, with low thermal conductivity and adequate thickness improving indoor temperature stability and reducing energy use. Results indicate that optimal insulation can increase indoor temperatures by up to 6 °C, substantially lowering heating demand. Expanded polystyrene (EPS) was selected for its favorable cost-performance ratio. The study emphasizes the importance of a comprehensive energy management strategy, integrating building orientation, window performance, and HVAC efficiency, to minimize energy consumption while ensuring optimal occupant comfort.

Keywords: building, optimization, Energy management, simulation, TRNSYS.

1 Introduction

Buildings account for approximately 40% of global energy consumption, primarily due to the extensive use of heating, ventilation, and air-conditioning (HVAC) systems [1,19], which are required to maintain thermal comfort and ensure adequate indoor air quality. This issue is particularly critical in countries with diverse climatic conditions, where energy demand for heating in winter and cooling in summer is substantial.

In Morocco, the building sector is among the most energy-intensive, representing more than 33% of total national energy consumption, with residential buildings accounting for approximately 26% and commercial buildings 7%, according to the latest data from the Moroccan Agency for Energy Efficiency (AMEE) [2]. This high level of consumption is further aggravated by the country's strong energy dependency, as more than 90% of its energy needs are met through imports. Consequently, improving energy efficiency in the building sector has become a major national priority [3].

To address this challenge, Morocco has implemented an ambitious regulatory framework through the introduction of the Thermal Regulation of Building Construction in Morocco (TRBM), approved by Decree No. 2-13-874 of October 15, 2014. This regulation aims to reduce energy consumption in new buildings by establishing minimum thermal performance requirements [3]. These requirements focus on thermal insulation, heating and cooling systems, and construction materials in order to limit heat losses and enhance energy efficiency.

Thermal comfort is defined as the condition in which occupants experience satisfaction with the indoor thermal environment. According to international standards and scientific studies, indoor temperatures of approximately 18 °C during heating periods and 21 °C during cooling periods are commonly considered acceptable comfort thresholds in building design [3].

A building envelope designed in accordance with local climatic conditions can lead to significant energy savings. In cold climates, thick and well-insulated walls are essential to reduce thermal losses [6,8,20]. Conversely, in hot climates, roofs with high thermal inertia help limit heat accumulation during sunny periods and contribute to maintaining acceptable indoor temperatures [7].

In cold regions, building envelope parameters play a crucial role in reducing energy consumption by limiting heat losses. Effective thermal insulation of walls, roofs, and windows helps maintain a stable indoor temperature without excessive heating demand. Wall thickness provides a protective barrier against external cold, while materials with high thermal mass, such as concrete and brick, are capable of storing and gradually releasing heat, thereby reducing indoor temperature fluctuations. This thermal inertia is particularly beneficial in cold climates characterized by large diurnal temperature variations [18].

Building energy modeling tools are essential for understanding thermal behavior and predicting the energy performance of different design configurations, allowing the selection of solutions adapted to local climatic conditions [19]. Several simulation tools are available, including TRNSYS, EnergyPlus, DesignBuilder, and Pléiades.

Among these tools, TRNSYS is widely used for building thermal simulations due to its flexibility and modular structure [20]. It relies on a multi-zone building model (Type 56), which enables the analysis of heat transfer, internal heat gains, ventilation, air infiltration, and thermal storage effects. TRNSYS also

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allows the modeling of HVAC systems and the integration of renewable energy technologies, such as solar thermal and photovoltaic systems [17].

Furthermore, TRNSYS enables the monitoring of indoor temperature evolution by considering various parameters, including local climate data, zone dimensions, building orientation, window-to-wall ratio, and envelope characteristics, in order to determine appropriate insulation strategies [4].

Despite the extensive literature on building energy simulation, most existing studies conducted in Morocco primarily focus on temperate or hot climatic zones [17,18], while cold mountainous regions remain insufficiently investigated. In particular, Climate Zone 4 (Ifrane), characterized by severe winter conditions and high heating demand, has received limited attention in previous research.

The novelty of this study lies in its focused assessment of building thermal performance in a cold Moroccan climate using dynamic TRNSYS simulations. Unlike earlier works that mainly emphasize annual energy consumption or regulatory compliance, this research highlights indoor temperature stability as a key performance indicator, providing a more direct evaluation of thermal comfort. Moreover, the combined analysis of insulation material type and insulation thickness enables a detailed understanding of their interactive effects on heat losses through the building envelope.

In contrast to previous Moroccan studies, which provide limited analysis of indoor temperature dynamics under severe winter conditions, the present work specifically targets a cold mountainous climatic context. By focusing on Climate Zone 4 (Ifrane), the study addresses a clear research gap and provides climate-specific insights that are not sufficiently explored in existing TRNSYS-based analyses.

In this study, the objective is to analyze indoor temperature variations and optimize building envelope parameters, such as insulation material type and thickness, to better understand the thermal behavior of buildings in a cold Moroccan climate. The study also proposes solutions to minimize heat losses through external walls. In parallel, passive energy management strategies are explored by integrating intelligent control approaches aimed at optimizing real-time energy demand and improving HVAC system operation.

Nomenclature:

AMEE: the Moroccan Agency for Energy Efficiency
HDD: Heating Degree-Days
CDD: Cooling degree days
TRBM: Thermal Regulation of Buildings in Morocco
DRF: Direct Root Finding
EPS: Expanded polystyrene

2 Climate Zoning in Morocco According to the TRBM

Morocco is divided into six different climatic zones (Table.1) based on the specific characteristics of each region. This classification was established by analysing meteorological data collected over a ten-year period (from 1999 to 2008) from 37 weather stations across the country [3].

2.1 Criteria for Climate Zoning

2.1.1 Heating Degree-Days (HDD)

This criterion measures the need for heating based on temperatures recorded during the winter season.
A higher value indicates a greater demand for heating.

Formula: $HDD = \sum(T_{base} - T_{daily\ average})$ (1)
Where:

$$T_{base} = base\ temprature = 18°C\ for\ heating$$

$$T_{daily\ average} = \frac{T_{max} - T_{min}}{2} \quad (2)$$

average outdoor temperature for the day
Only values where $T_{daily\ average} < T_{base}$ are considered.

2.1.2 Cooling degree days (CDD):

This criterion measures the need for cooling based on the maximum temperatures recorded during the summer. a higher number indicates a higher demand for air conditioning.

Formula: $CDD = \sum(T_{daily\ average} - T_{base})$ (3)
Where:

$$T_{base} = base\ temprature = 21°C\ for\ Cooling$$

$$T_{daily\ average} = \frac{T_{max} - T_{min}}{2}$$

average outdoor temperature for the day
Only values where $T_{daily\ average} > T_{base}$ are considered.

Based on this data, each region is assigned to a specific climatic zone. Tailored recommendations are provided for building insulation and energy efficiency, considering the region's heating and cooling needs. This zoning system results in six distinct climatic zones summarized in the following table.

Table 1. Climatic Zones of Morocco.

Climatic zone	**Cities**	**HDD (°C·day)**	**CDD (°C·day)**
Zone 1(very hot)	Agadir	0-200	> 4000
Zone 2 (hot)	Tangier	200-500	3000-4000

Zone 3 (hot temperature)	Fes	500-1000	2000-3000
Zone 4 (cold temperature)	Ifrane	1000-1500	1000-3000
Zone 5 (cold)	Marrakech	1500-2500	< 1000
Zone 6 (very cold)	Errachidia	> 2500	0

In a city like Ifrane, located in the mountains, winters are harsh with temperatures often below 0°C. This results in a high number of heating degree-days, indicating a significant need for heating.

3 Mathematical descriptions

3.1 The Equation for Convective Heat Flux to the Air Node

TRNSYS is a simulation tool used to analyse the thermal performance of buildings.

Within this software, the temperature of the indoor air is determined by evaluating the total heat exchange occurring at the "air node".

This heat balance, noted Q_n, is obtained by summing all heat gains and losses affecting the room:

$$Q_n = Q_{surf,n} + Q_{inf,n} + Q_{vent,n} + Q_{g,c,n} + Q_{cplg,n} + Q_{solair,n} + Q_{ishcci,n} \qquad (4)$$

Where:$Q_{surf,n}$ heat exchanged with the internal surfaces (walls, ceiling, floor); $Q_{inf,n}$ heat flow due to infiltration (air leakage); $Q_{vent,n}$ heat added or removed by the ventilation system ;$Q_{g,c,n}$ internal heat gains (occupants, lighting, equipment); $Q_{cplg,n}$ heat transferred from adjacent thermal zones ; $Q_{solair,n}$ solar radiation entering through glazing; $Q_{ishcci,n}$ heat absorbed or released by internal shading devices.

For the purpose of the present study, this energy balance has been simplified.All contributions except the heat exchange with the surrounding surfaces were neglected.

The equation therefore reduces to:

$$Q_n = Q_{surf,n} \qquad (5)$$

3.2 Heat Exchange Through Surfaces

to estimate the heat transfer between the room and the building envelope, TRNSYS employs the transfer function method originally proposed by Mitalas and Arsenault.

This approach represents the internal and external heat fluxes using recursive relations that account for both current and past thermal states of the wall.

The internal heat flux is expressed as:

$$q_{surf,i} = \sum_{k=0}^{n_{b_s}} b_s^k T_{s,o}^{(k)} - \sum_{k=0}^{n_{c_s}} c_s^k\, T_{s,i}^{(k)} - \sum_{k=1}^{n_{d_s}} d_s^k\, q_{surf,i}^{(k)} \qquad (6)$$

Similarly, the external heat flux is given by:

$$q_{surf,o} = \sum_{k=0}^{n_{a_s}} a_s^k T_{s,o}^{(k)} - \sum_{k=0}^{n_{b_s}} b_s^k\, T_{s,i}^{(k)} - \sum_{k=1}^{n_{d_s}} d_s^k\, q_{surf,o}^{(k)} \qquad (7)$$

Where:

- $q_{surf,i}$, $q_{surf,o}$: internal and external heat fluxes
- $T_{s,o}$,$T_{s,i}$: interior and exterior surface temperatures
- a_s , b_s , c_s, d_s : transfer function coefficients
- $k = 0$: current time step
- $k > 0$: previous time steps

These coefficients are automatically computed by TRNSYS using **the Direct Root Finding (DRF) algorithm** [16].

3.3 Windows Case

Glazed surfaces are processed in TRNSYS in the same way as external walls but, due to their extremely low thermal mass, the dynamic effects are negligible.

Consequently, the transfer function reduces to a static representation:

$$a_s^0 = b_s^0 = c_s^0 = d_s^0 = U_{g,s} \qquad (8)$$

$$a_s^k = b_s^k = c_s^k = d_s^k = 0 \quad for\ k > 0 \qquad (9)$$

where $U_{g,s}$ is the thermal transmittance (U-value) of the glazing.

3.4 Initialization

- The surface temperatures (internal and external) and the thermal zone start at 20°C.
- Initial heat fluxes are set to zero.
- Temperatures and fluxes from previous time steps are also initialized to 20°C and zero

4 TRNSYS Simulation

TRNSYS Simulation of Daily Maximum and Minimum Temperature Variations for Three Zones (Agadir, Ifrane, Errachidia) over one year.

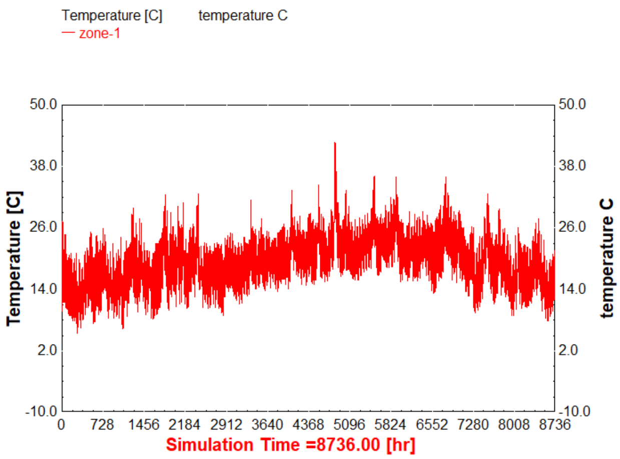

Fig. 1. Zone 1- Agadir

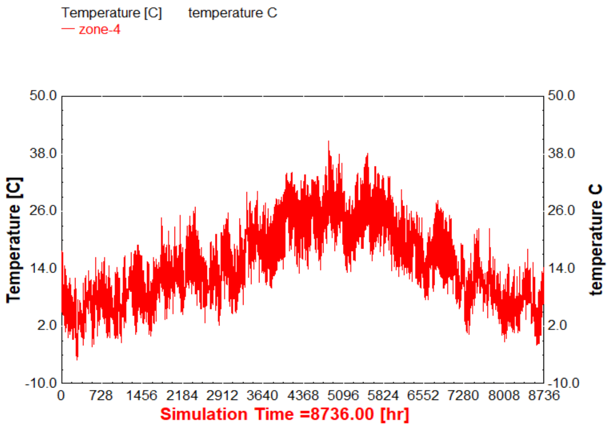

Fig. 2. Zone 4- Ifrane

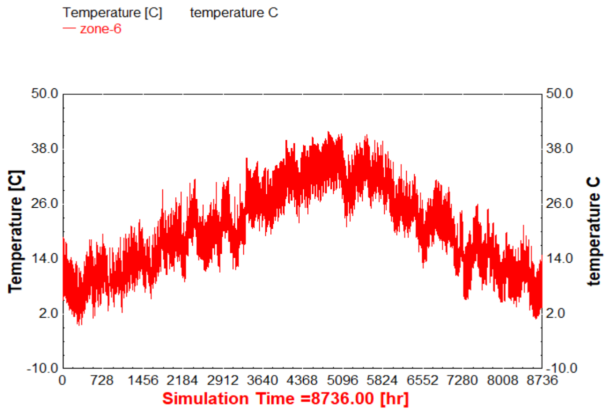

Fig. 3. Zone 6- Errachidia

The analysis emphasizes the need to consider these temperature variations in building design and energy management. The data can help optimize heating and cooling systems tailored to each region's specific needs, enhancing energy efficiency. By using this data, each region was assigned to a specific climatic zone, accompanied by tailored recommendations for insulation and energy efficiency in buildings based on its heating and cooling needs.

4.1 Energy management in zone 4 -Ifrane

In Zone 4, specifically in Ifrane, several key parameters influence energy consumption in buildings. These include thermal insulation, building orientation, window specifications, and the efficiency of heating, ventilation, and air conditioning (HVAC) systems. To minimize energy consumption in this mountainous region, it is essential to enhance insulation using high-quality materials to reduce heat loss during the harsh winters.

4.1.1 Choice of adequate insulation

The city of Ifrane located in climate zone 4, where the climate is relatively cold in winter and moderate in summer, it is essential to choose an insulating material with good thermal resistance. According to the Thermal Construction Regulation in Morocco, the minimum adequate thermal resistance for zone 4 is ≥ 1.25 $m^2.k/W$ [3] .Here are some proposals for materials.

Table 2. Insulating Materials for Ifrane

Material	**Thermal conductivity λ (W/m.K)**	**Recommended Thickness (cm)**	
		Walls	**Roofs**
wood wool	λ≈ 0.035	10-15	15-20
Glass Wool	λ≈ 0.032	10-15	15-20
Expanded polystyrene (EPS)	λ≈ 0.038	8-12	12-15
wood fiber	λ≈ 0.040	12-15	15-22

To select an appropriate insulation material for our house in Ifrane, we will conduct a simulation using TRNSYS.

We will consider a simplified geometry—a closed room with the following dimensions: height 3m, width 4m, and length 9m.

The simulation under TRNSYS allows for the analysis and comparison of the thermal behavior of insulating materials (Table.2), taking into account several specific parameters, such as the material's **thermal conductivity**, which determines its ability to transmit heat, as well as **the thickness** of the insulation, which influences the overall thermal resistance. By varying these two parameters, TRNSYS allows observation of how changes in the type of insulating material and its thickness affect **the temperature fluctuations** inside the simulated room.

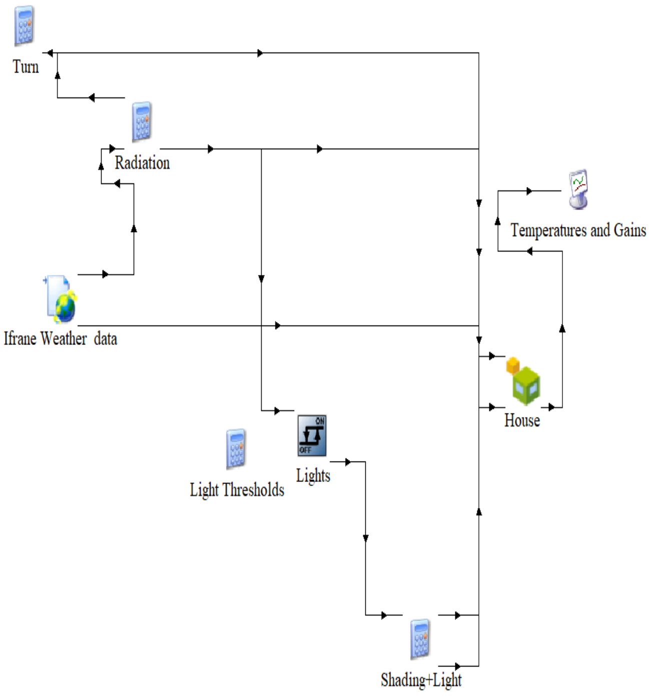

Fig. 4. TRNSYS simulation interface map

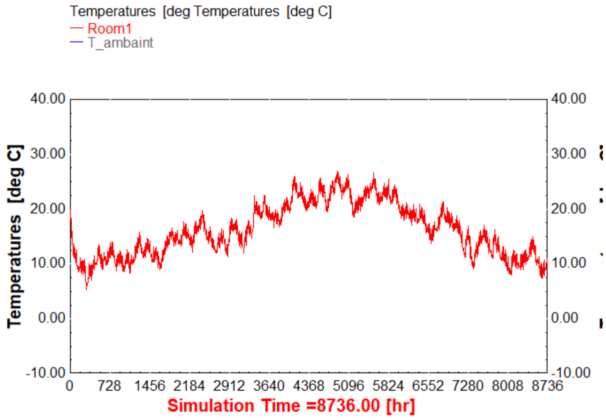

Fig.5. Temperature variation in the study area without insulation

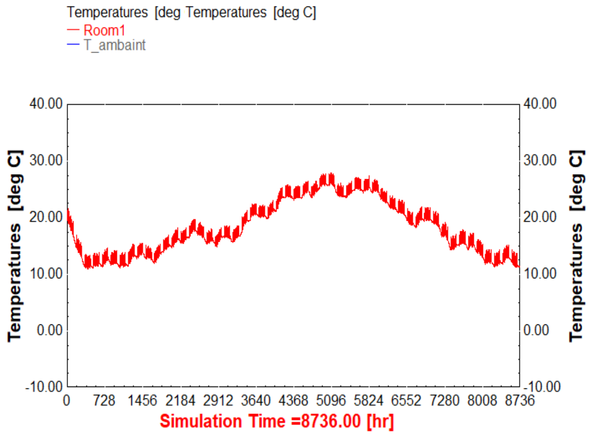

Fig.6. Temperature variation in the study area with insulation (wood wool, thickness=10cm)

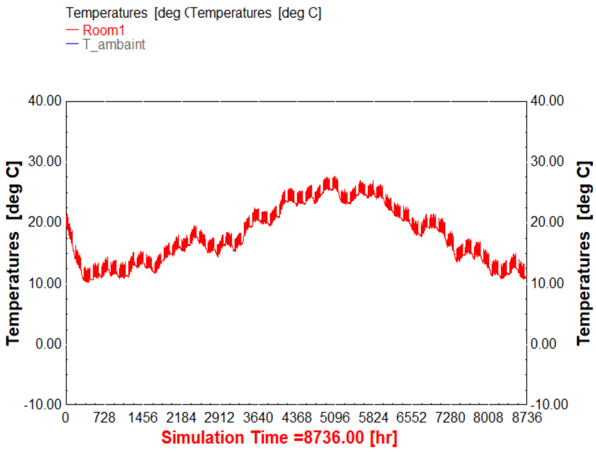

Fig.7. Temperature variation in the study area with insulation (EPS, thickness=10cm)

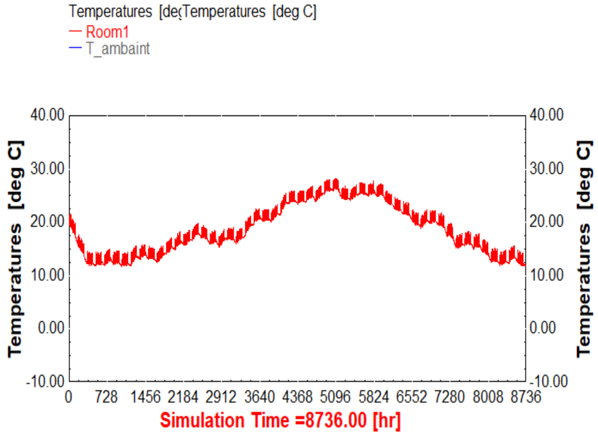

Fig.8.Temperature variation in the study area with insulation (EPS, thickness=15cm)

4.1.2 the role of insulation

The comparison between Figures 5 and 6 clearly illustrates the impact of insulation on thermal performance. Figure 5 shows significant heat loss through the walls in the study area without insulation, resulting in increased energy consumption for heating during colder months and higher energy bills.

In contrast, Figure 6 presents the same area with insulation using wood wool, revealing a notable reduction in heat loss. The insulating properties of wood wool help maintain a stable indoor temperature, enhancing energy efficiency and contributing to a more comfortable living environment by preventing cold drafts.

4.1.3 choice of adequate insulation

The comparison between Figures 6 and 7 shows that insulation with wood wool has almost the same effect as insulation with polystyrene. However, upon closer observation, we see that the fluctuations in Graph 6 are lower compared to Graph 7. This confirms that when conductivity is low, we have a good insulator.

4.1.4 the effect of insulation thickness

The comparison between Figures 7 and 8 illustrates the impact of insulation thickness on heat loss through the walls. It is evident that, for the same insulator, such as EPS, heat loss decreases when the thickness increases from 10 cm to 15 cm. Therefore, an increase in thickness contributes to improved thermal performance.

5 Conclusion

The thermal simulations conducted using TRNSYS for the city of Ifrane (Climate Zone 4) clearly demonstrate the critical role of thermal insulation in improving building energy performance in cold Moroccan climates. The results show that, in the absence of insulation, the studied room experiences significant heat losses, leading to pronounced indoor temperature fluctuations and reduced thermal comfort.

The introduction of thermal insulation with appropriate thickness substantially improves indoor thermal conditions. In particular, the use of wood wool as an insulating material significantly reduced temperature variations, achieving an indoor thermal gain of approximately 6 °C compared to the uninsulated case. Its thermal performance was found to be comparable to that of expanded polystyrene (EPS), while exhibiting slightly lower temperature variability, highlighting the importance of low thermal conductivity materials in minimizing heat transfer through the building envelope.

Furthermore, the influence of insulation thickness was clearly observed. Increasing the EPS insulation thickness from 10 cm to 15 cm enhanced the thermal resistance of the envelope, resulting in further reductions in heat losses and improved indoor temperature stability. These findings confirm that both insulation material selection and thickness optimization are key parameters for achieving efficient thermal performance in cold climates.

The main scientific contribution of this study lies in its targeted application of dynamic TRNSYS simulations to evaluate indoor temperature stability and thermal comfort in a cold Moroccan climatic zone, which remains insufficiently addressed in previous Moroccan studies. Unlike earlier TRNSYS-based analyses that mainly focus on annual energy demand or regulatory compliance, this work emphasizes indoor temperature behavior under severe winter conditions as a primary performance indicator.

In addition, the combined assessment of insulation material type and insulation thickness within the same climatic context provides a more comprehensive understanding of their interactive effects on heat losses through the building envelope. This approach delivers climate-specific and practical recommendations for building design and retrofitting in cold mountainous regions, while enhancing the applicability of TRNSYS as a decision-support tool for energy-efficient buildings and supporting the implementation of the Moroccan Thermal Regulation of Building Construction (TRBM).

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