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Energy Efficiency of Residential Buildings in Cold and Dry Climates using Simulation-based Comparative Analysis: Case Study in Tabriz

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P A P E R I N F O

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A B S T R A C T

The purpose of this research is to analyze the energy of a residential building in the city of Tabriz with a cold and dry climate using energy simulation to provide a model to minimize energy consumption. A comparative model of energy consumption analysis in a three-story building unit with dimensions of 181 square meters is presented using 5 layout modes in the wall, floor, ceiling, window and door. The number of 5 designs with different arrangement of rooms and different number of windows were compared in terms of energy conservation in 51 different diagrams and the optimal energy saving design is selected. In the next step, according to the obtained results, the design of the building in the desired site is discussed. At the end, in order to check the amount of energy absorbed in the building, energy diagrams will be obtained for the thermal region of the coldest day of the year. The results show that the most optimal energy consumption of the residential building is related to the design of plan B with the fabric gains value of 41767 Wh. After that, the designed plan A show the most optimal energy consumption in the building with fabric gains value of 41028 Wh in the month of July. The results of this research are useful for energy efficiency of residential buildings and environmental management in future.

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INTRODUCTION

Buildings are responsible for approximately 40% of the world's total energy consumption and carbon emissions, making this a critical and prevalent issue in today's global context (1). In fact, around 27% of carbon dioxide (CO_2) emissions in developing countries can be attributed to buildings, primarily due to heat loss within residential structures (2, 3). The significance of the built environment extends beyond energy consumption during construction and occupancy (4). It also garners substantial attention from governments, occupants, and stakeholders who are keen on improving the energy efficiency of buildings (5, 6). Building design strategies (BDS) play a pivotal role in addressing this challenge and are applied in three primary areas: environment, climate, and energy. These strategies are essential for achieving energy conservation goals (7). Building energy simulation stands out as a commonly employed method for quantitatively assessing the relationship between carbon emissions and various building designs (8). To gain a comprehensive understanding of building energy efficiency, a thorough review was conducted, encompassing previous research that utilized simulation software (9–11). Also, a series of researches have been done in the field of energy efficiency of residential buildings using energy simulation model (12–14). In addition to the mentioned researches, various studies have been conducted in connection with the performance of building material science in the efficiency of energy consumption and renewable energies (15, 16). Other studies have been conducted in connection with the management of building renewable energy using photovoltaic power plants system (17, 18). In other studies conducted by researchers, renewable energy management was implemented using dynamic decision-making algorithms

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(19, 20). In the latest research, scientists achieved optimal models of energy consumption through the Energy Plus (21–23), E-Quest (24), and DesignBuilder (25) simulation system in the building using validation tools. Some other researchers have reached the optimal models of energy consumption through the building information modeling system (26–28). The present study addresses the critical aspects of energy conversion and efficiency in the context of residential building design using Ecotect simulation software for modeling and simulation. A comprehensive analysis of prior research reveals a conspicuous gap in the literature: the absence of comparative studies on residential building designs and their impact on reducing gas consumption within cold winter zones worldwide, utilizing simulation software. While numerous studies have explored the enhancement of indoor thermal conditions in residential buildings, the primary focus has predominantly centered on buildings situated in moderate climates. Only a limited number of investigations have delved into the realm of residential buildings in cold and dry climate conditions, where computer simulations are employed to achieve energy efficiency (29). It is noteworthy that Tabriz city in Iran experiences distinctive seasonal and daily climatic patterns, characterized by average cold and dry temperatures, in contrast to the temperate climates of European cities. The principal objective of this study is to analyze the energy performance of residential buildings through energy simulations. The ultimate goal is to formulate a model that can effectively reduce energy consumption through design modifications. This comprehensive review was conducted in Tabriz city, Iran, during the period spanning 2020-2021.

MATERIALS AND METHODS

The initial phase of our methodology encompasses data collection and site analysis conducted during the coldest period of winter within a cold-dry climate. This phase comprises two key components: first, the compilation of annual temperature data, and second, the gathering of comprehensive information regarding building components. This information encompasses the properties of building materials, construction details, and foundational design elements. These datasets serve as the basis for generating computer simulations designed to evaluate various design options explored in this study. Subsequently, we proceed to the next stage, which involves a comparative analysis of energy consumption models within a three-story building unit spanning 181 square meters. We explore five distinct layout configurations, considering variations in the arrangement of walls, floors, ceilings, windows, and doors. We compare these five designs, each with differing room arrangements and window counts, across 51 different scenarios, with the goal of identifying the most energy-efficient design. To accomplish this, we leverage building energy simulation tools such as EnergyPlus, Ecotect, and eQuest, which play a pivotal role in modeling the energy performance of existing structures and investigating retrofit options (30). Based on the findings derived from our analyses, we engage in a comprehensive discussion concerning the building's design within the specified site. In conclusion, to assess the building's energy absorption capacity, we generate energy diagrams that depict the thermal characteristics of the building during both the coldest and hottest days of the year.

Weather data

The city of Tabriz, located at coordinates 38°.08' N and 46°.15' E, is situated at an elevation of 1350 meters above sea level. Tabriz experiences a cold-dry climate characterized by extremely low temperatures during the winter months, particularly from December to February. Conversely, summer temperatures are quite moderate, with a maximum typically reaching 26 °C (31, 32). For reference, the maximum and minimum temperatures recorded in Tabriz during the coldest month of the year, January, over a span of ten years (2010-2020), ranged from 15 °C to -19.6 °C (31, 32). Figure 1 illustrates the weather data collected over this decade, sourced from local weather stations, and serves as a representative dataset for the region (33). These weather data points are crucial inputs for our thermal modeling efforts, allowing us to predict annual energy consumption for various weather scenarios. This, in turn, enables us to evaluate potential energy-saving strategies for atrium design options. To perform this analysis, we input the relevant weather data into the Ecotect weather tool, which can automatically generate detailed climate analysis results specific to Tabriz.

The city of Tabriz positioned at a latitude of 38.8° north, 46.28° east. Its geographical location places it in a highly advantageous position for receiving solar

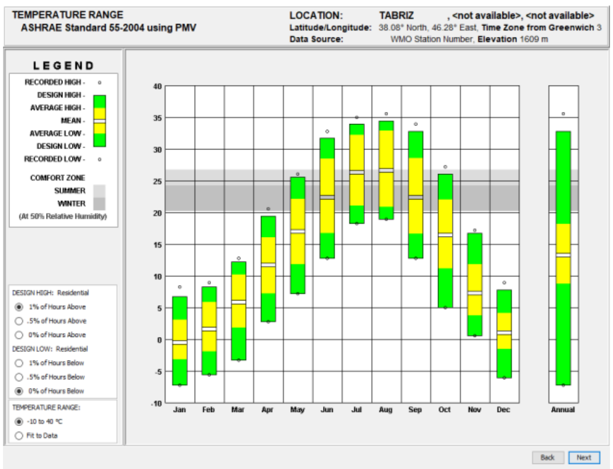


Figure 1. The maximum and minimum air temperature of Tabriz city

radiation. As a result, assessing the duration of sunshine hours and the angle of solar radiation throughout the day across different seasons is a critical aspect of calculating and evaluating the amount of solar radiation available for various applications. Figures 2 and 3 provide valuable visual representations of this information. Figure 2 displays the direction of the sun, indicating its path across the sky, while Figure 3 illustrates the changing angles of solar radiation throughout the day. These figures, sourced from (31, 32) are instrumental in understanding the solar dynamics in Tabriz, aiding in the design and utilization of solar energy systems, as well as in various other applications that rely on solar radiation data.

The initial output of the software, which encompasses essential data such as wind and sun information, is visually represented in the following four figures: Figures 4 and 5 provide insights into this data. To ensure the accuracy and reliability of the input data, we employed Climate Consultant 6.0 software. This software offers a comprehensive analysis of climate data and allows for a more thorough validation of the climate conditions in Tabriz. The climate data used in Climate Consultant 6.0 was directly extracted from the Ecotect website, guaranteeing the precision and authenticity of Tabriz climate data utilized in our analysis.

Case study

The energy simulation is conducted on a residential building comprising three-story. The building unit covers an area of 181 square meters and has a length of 3 meters. The building has a door on the east side with an area of 1.8 square meters.

These specifications provide the necessary details for the energy simulation, enabling the assessment of the building's energy performance and its response to various design and climate factors. Table 1 presents the required materials for modeling and simulation.

In the context of residential usage, it is assumed that there are five occupants in each story of the building, and these occupants are present full-time throughout the entire year. Additionally, it's mentioned that there is ample natural lighting available for all spaces within the

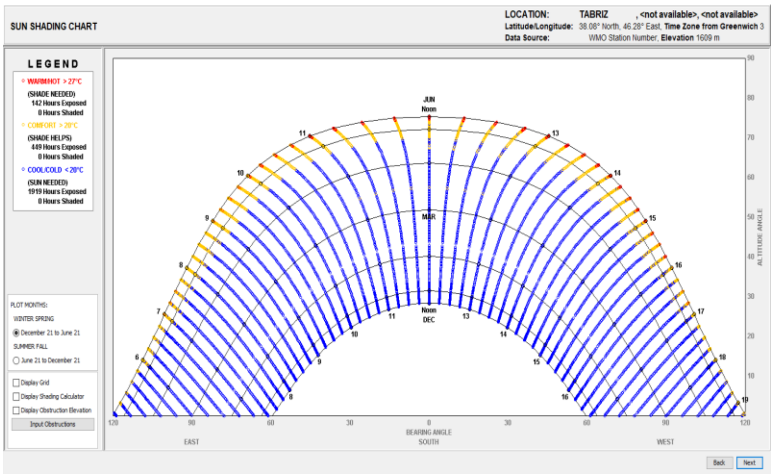


Figure 2. The direction of the sun of Tabriz city

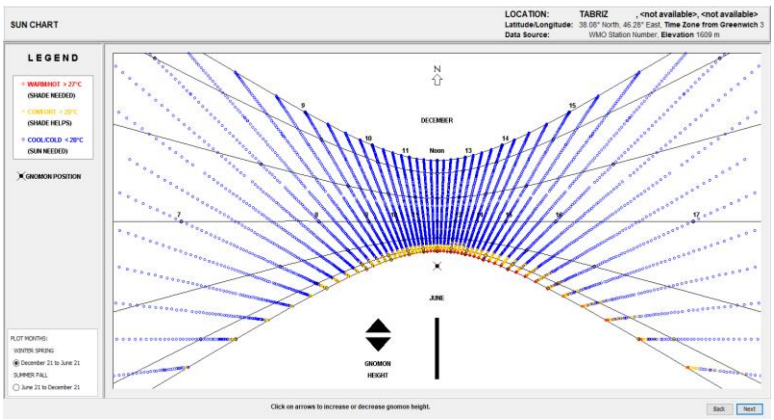


Figure 3. The angel of the sun of Tabriz city

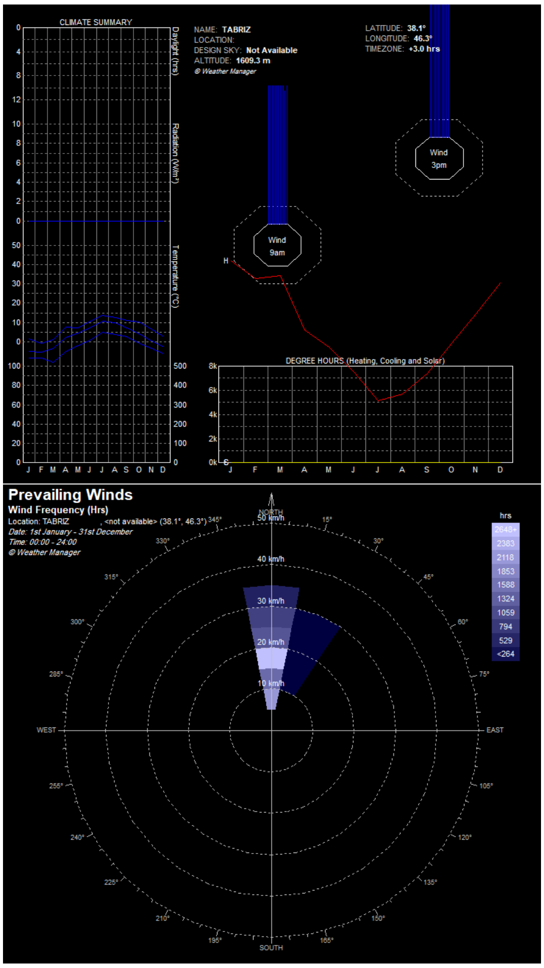


Figure 4. Climate data analysis in Ecotect software

building. This assumption implies that the building's design and layout are such that it maximizes the use of natural daylight, reducing the reliance on artificial lighting during daytime hours. This approach not only promotes energy efficiency but also enhances the overall comfort and livability of the residential spaces.

Input data parameter

In the process of selecting the best design for a cold climate, the following steps were undertaken:

Model Drawing and Material Selection: The design of the building was created, and appropriate materials were selected to ensure energy efficiency and thermal performance.

Hourly Weather Data: Hourly weather data for the city over the past ten years were obtained from the internet. This data is crucial for conducting accurate thermal analysis.

Thermal Analysis with Ecotect: The thermal analysis process was initiated using Ecotect software. Ecotect provides various outputs and insights, including:

- Hourly temperature changes graph.
- Building external cover radiation for different times and months.
- Distribution of energy attraction and thermal waste in the building's area.
- Temperature distribution in different areas of the building.
- Calculation of thermal interchange attraction and construction waste for each month.

Thermal Comfort Analysis: The study also involved the calculation of thermal comfort conditions. These calculations were based on Ecotect analysis, taking into account both personal and environmental factors. Figure 6 illustrates the steps involved in entering data into the software.

Table 2 provides information on the settings and limitations used to define thermal comfort areas within the building.

These comprehensive analyses and calculations are crucial for optimizing the building design to ensure that it

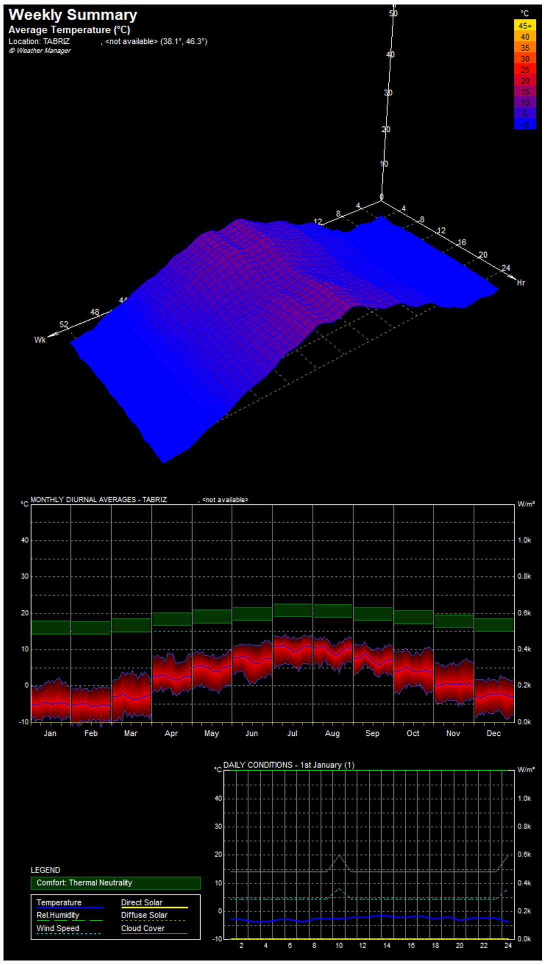


Figure 5. Monthly average thermal insulation and average temperature in Ecotect software

Table 1. The definitions of the materials

	U-Value (w/m2k)	Admittance (w/m2k)	Solar Absorption (0-1)	Visible Transmittance (0-1)	Thermal Decrement (0-1)	Thermal Lag (hrs)	(SBEM) CM1	(SBEM) CM2	Thickness (mm)	Weight (kg)	Emissivity	Specularity	Roughness	Refractive index of Glass	Alt solar Gain (Heavywt)	Alt solar Gain (lightwt)
Wall: brick cavity concrete block plaster	1.720	4.220	0.428	0	0.41	7.8	0	0	280.0	408565	0.9	0	0	-	-	-
Glaze: double glazed alum frame	2.700	2.800	0.81	0.639	-	-	-	-	0	0.000	0.78	0	0	1.74	0.42	0.56
Floor: concrete slab on ground	0.880	6	0.467	0	0.3	4.6	0	0	0	0	0.9	0	0	-	-	-
Void	5.618	10	0.001	0.999	1	0	0	0	0	0	0.86	0	0	-	-	-
Ceiling: plaster insulation suspend	0.500	0.900	0.368	0	0.32	0.7	0	0	210	13.295	0.9	0	0	-	-	-

Table 2. Software configuration

Setting of the areas thermal comfort limitations
1) People clothes in work continuous situation
2) Internal relative humidity amount with due attention to field studies and comfort domain
3) Wind current speed
4) Weather data watch to watch ten years of considered cities accordance to ECOTECT format
5) lightening amount for passageway space and lights inter
6) Average of present people number in light thermal area
7) Energy inexpert for walking activity into light
8) Amount of internal attraction
9) Accessible amount of the wind
10) Schedule of beginning works and time and keep silent installation in light adjacent spaces
11) Comfort domain of official spaces temperature

meets thermal comfort standards while also maximizing energy efficiency in a cold climate. By systematically assessing these variables and conducting thorough analyses, the study aims to recommend the most suitable building design for residential buildings in cold and dry climates. The goal is to optimize lighting, energy efficiency, and thermal comfort to create comfortable and sustainable living spaces.

RESULTS AND DISCUSSION

Ecotect software

The choice of Ecotect software for conducting simulations in the research is well-founded and supported by previous studies and research practices (34, 35). Here are some key points highlighting the advantages and capabilities of Ecotect. High Accuracy: Ecotect simulations are widely recognized for their high level of accuracy. The trust placed in this software by researchers is a testament to its reliability in predicting building performance (36). Comprehensive Analysis: Ecotect offers a comprehensive set of performance analysis functions, making it a versatile tool for evaluating various aspects of building performance, including thermal, lighting, and acoustic analyses (37). 3-D Design Interface: The software combines a user-friendly 3-D design interface with analysis functions, making it intuitive for designers and architects to work with. This feature aids in integrating performance analysis seamlessly into the design process (38). Performance Metrics: Ecotect provides a range of performance metrics, including hourly thermal comfort, monthly space loads, natural and artificial lighting levels, acoustic reflections, reverberation time, project costs, and environmental impact. This wealth of data enables researchers to assess building performance comprehensively. Sustainability and Cost Benefits: Ecotect simulations can contribute to designing buildings that reduce global warming potentials and lower operational costs. This is a significant advantage, especially in today's environmentally conscious and cost-conscious building industry. Early-Stage Analysis: The ability to simulate building performance during the design stage is invaluable. It allows architects and designers to make informed decisions that can lead to more sustainable and efficient building designs. Environmental Analysis: Ecotect is particularly well-suited for environmental analysis, including solar exposure, energy distribution, temperature distribution, and heat loss/gain assessments. This capability is essential for understanding a building's environmental impact and energy efficiency (39). Overall, the selection of Ecotect as the analysis software for the study appears to be a sound choice, given its robust capabilities and track record in building performance analysis. It aligns well with the goals of improving building sustainability and reducing operational costs while providing accurate insights into various performance aspects.

Modeling

In the first step of the research, a base design inspired by existing buildings in Tabriz city was used as the starting point. This base design was then replicated across multiple floors. Let's take a closer look at the different design plans mentioned:

Plan A: The initial design is characterized by a parking lot and a staircase on the first floor. The upper floors feature bedrooms in the northern part of the building and a hall area in the southern part. This design aims to preserve the existing building pattern and layout.

Plan B: In this variation, the interior design of the second floor was modified. Changes were made to the location and number of windows on this floor.

Plan C: Plan C involves simultaneous changes to the second and third floor layouts, including alterations to the number and placement of windows.

Plan D: This plan introduces changes to the layout of rooms, the kitchen, and the placement of windows. Although the general layout across the three floors remains the same, it differs from the basic design in specific aspects.

Plan E: In Plan E, the location of the kitchen on the first floor is shifted, while the layouts of the other two floors remain unchanged.

Figure 7 provides a visual representation of the base design (Plan A) of the residential building in Tabriz city. Figure 8 showcases the modeling of the base plan of the building in various design modes, which are intended for analysis and comparison of energy consumption using Ecotect software.

These different design plans offer a way to explore how variations in building layout and interior design impact energy consumption and overall building performance. By comparing these plans, it can identify which design best aligns with the objectives in terms of energy efficiency, comfort, and functionality in the context of a cold and dry climate.

Figure 8 displays the modeling of Plan A, the base design, in various design modes. These different design modes are analyzed and compared using Ecotect software to evaluate their energy consumption and performance. This comparative analysis aims to identify which design mode offers the most efficient and sustainable energy use within the context of the cold and dry climate of Tabriz city.

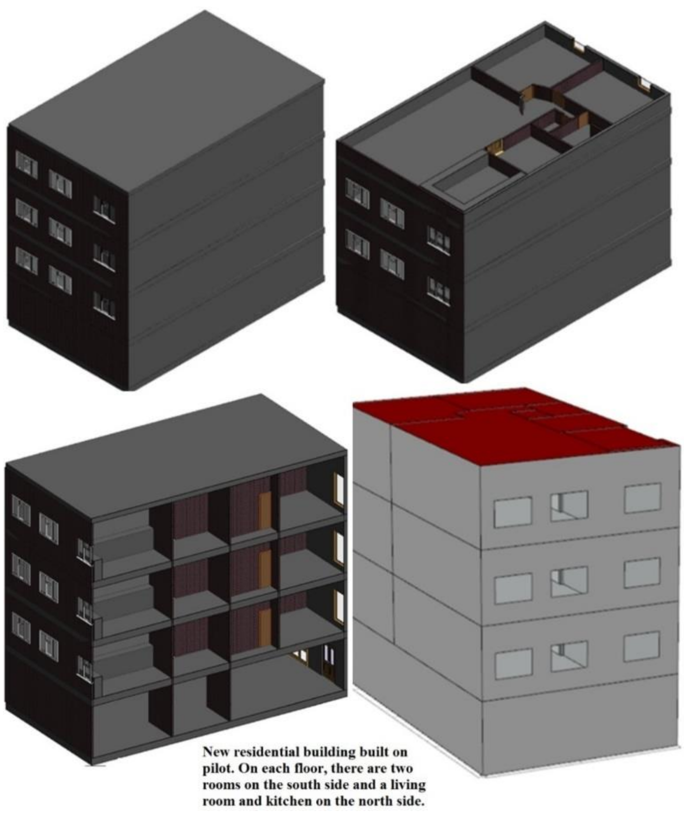


Figure 7. Plan A of residential building in Tabriz city

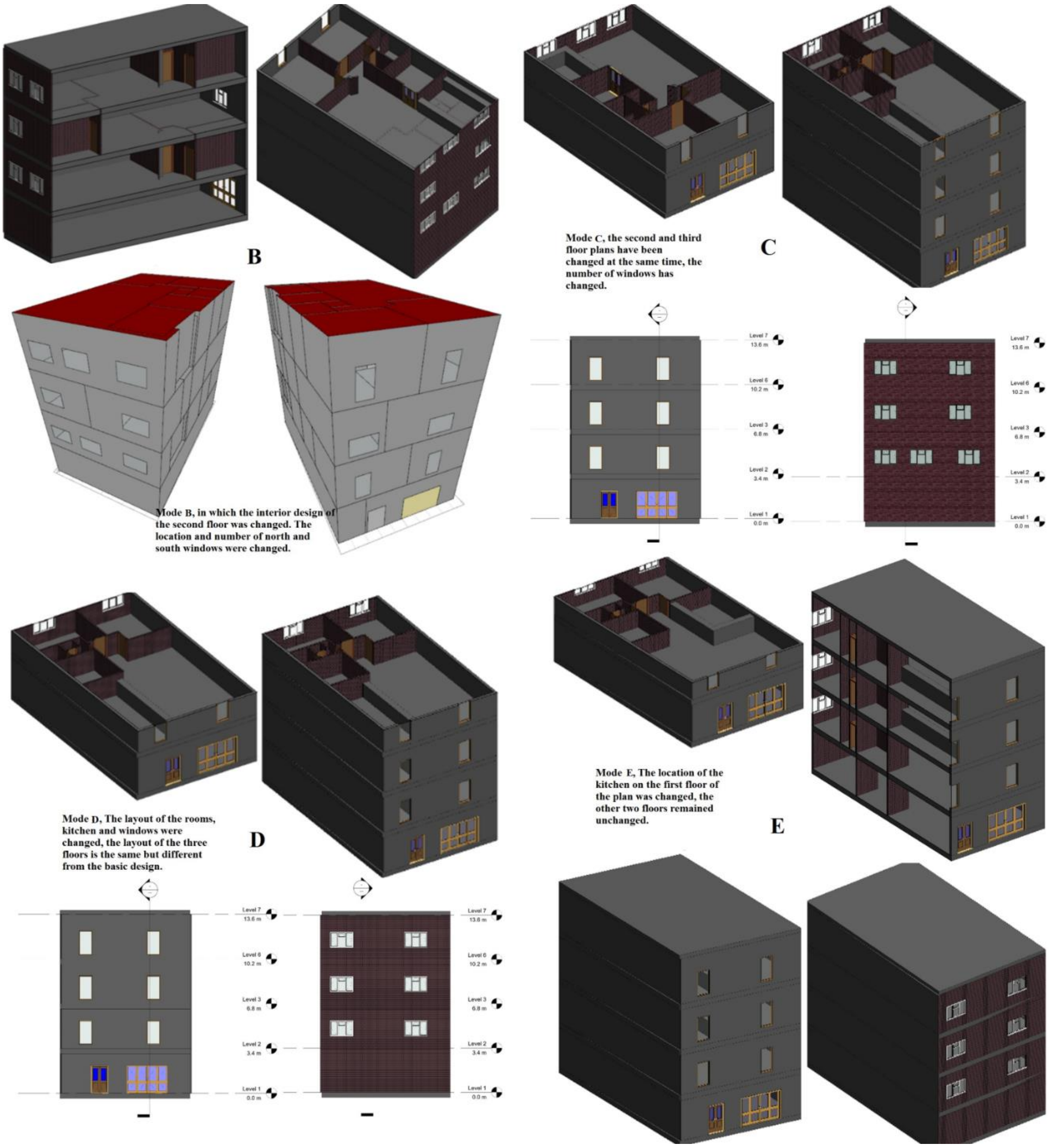


Figure 8. Design of 4 different modes of residential buildings in Tabriz city for analysis and comparison of energy consumption in Ecotect

Software analysis and simulation

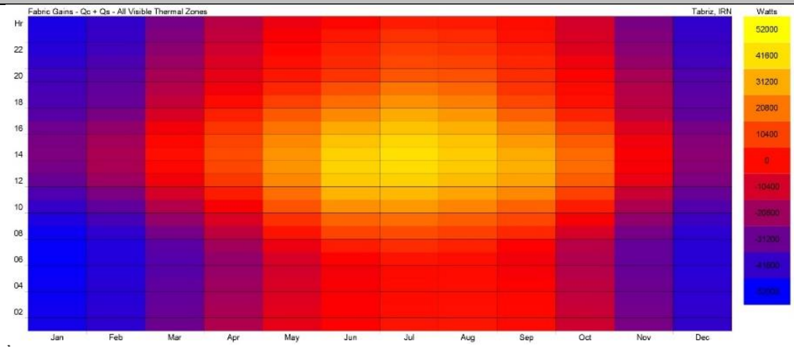
The simulation results, based on the analysis of four different modes in the residential building of Tabriz city, provide valuable insights into energy gains and losses. Figure 9 illustrates the graph of fabric gains, with the left side showing working hours and the right side displaying the values of fabric gains. In this graph, yellow represents absorption, while blue represents thermal waste. Here are some key findings from the energy analysis:

Energy Changes Throughout the Day and Year: The analysis evaluates energy absorption changes over a 24-hour period and across twelve months of the year. This comprehensive approach allows for a detailed understanding of how energy performance varies with time.

Variations in Building States: The study assesses five different simulated building states, which likely represent variations in room arrangement and window configurations. These variations are important for understanding how design choices impact energy absorption.

Significance of Room and Window Arrangement: The research highlights the significance of changes in the arrangement of rooms and windows in influencing energy

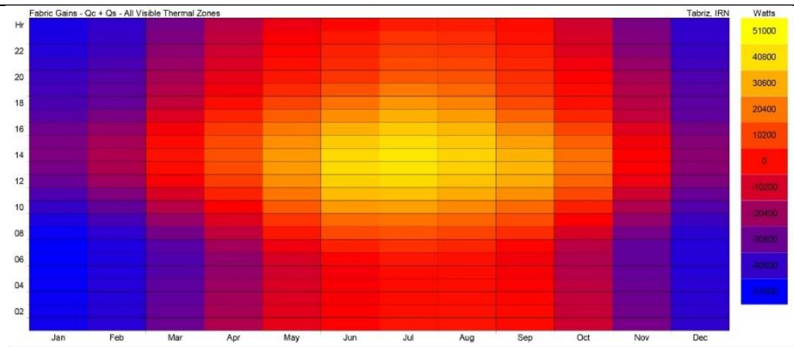
Fabric Gains	Plan



ANNUAL LOADS TABLE
Fabric Gains - Qc + Qs
All Visible Thermal Zones - Monthly Averages

HOUR	JAN (Wh)	FEB (Wh)	MAR (Wh)	APR (Wh)	MAY (Wh)	JUN (Wh)	JUL (Wh)	AUG (Wh)	SEP (Wh)	OCT (Wh)	NOV (Wh)	DEC (Wh)
00	-47939	-43371	-30501	-17569	-6706	-2008	1346	1422	-532	-11735	-28498	-42116
01	-48745	-43837	-31612	-18875	-7676	-2564	413	650	-854	-12914	-29413	-42507
02	-49579	-44319	-32611	-19985	-8697	-3051	35	337	-1307	-13945	-30305	-42951
03	-50045	-44128	-33322	-21134	-9535	-3360	-153	94	-1920	-14903	-30709	-43394
04	-50688	-44971	-34772	-22850	-11019	-4096	-427	-266	-3731	-16475	-31704	-43922
05	-51086	-45342	-35482	-23379	-9920	-2207	1278	169	-4729	-17288	-32196	-44096
06	-51213	-45428	-34403	-20325	-5700	3096	6217	4088	-2021	-15966	-32199	-44203
07	-49766	-42826	-28768	-14589	1226	10881	12357	10074	5465	-9956	-28756	-43332
08	-46056	-38087	-22922	-9291	6919	16871	18677	15932	11465	-3573	-23514	-40074
09	-41358	-32910	-16959	-3251	13962	26035	27406	23164	16853	2878	-18020	-35819
10	-36618	-27544	-10362	3053	19226	32604	33599	29401	24277	10453	-12610	-31628
11	-31619	-21399	-4485	8254	23991	36864	38282	34237	29516	15888	-6166	-27228
12	-28787	-18655	-1052	11410	26283	38571	40631	36939	31790	18513	-3340	-25234
13	-27525	-18511	90	12151	26341	38325	41028	37294	31024	18339	-3131	-24702
14	-27962	-19970	-1248	10906	24005	35510	39294	35514	27755	15340	-4988	-25753
15	-30195	-23353	-4530	7985	20062	30735	35698	32078	22593	10313	-8690	-28568
16	-34727	-27970	-9478	3838	14877	24476	30888	27070	16500	4467	-14307	-32839
17	-36857	-31844	-13836	-486	9967	18755	25976	22481	11337	531	-15689	-33557
18	-38168	-32935	-16758	-4724	5095	13040	20533	17401	7997	-402	-16989	-34587
19	-39460	-34730	-18970	-6934	1962	7674	14221	13302	6486	-2088	-18897	-35960
20	-42161	-36971	-21790	-9404	284	5614	11397	10450	4949	-4871	-22498	-38928
21	-44610	-39671	-24419	-11789	-1506	4072	9135	8006	3209	-8517	-25191	-40272
22	-45968	-40958	-27069	-14247	-3315	2327	7216	5802	638	-9727	-26682	-41362
23	-46769	-42071	-28742	-15956	-5526	-1363	2837	2750	-208	-11005	-27926	-42106

A



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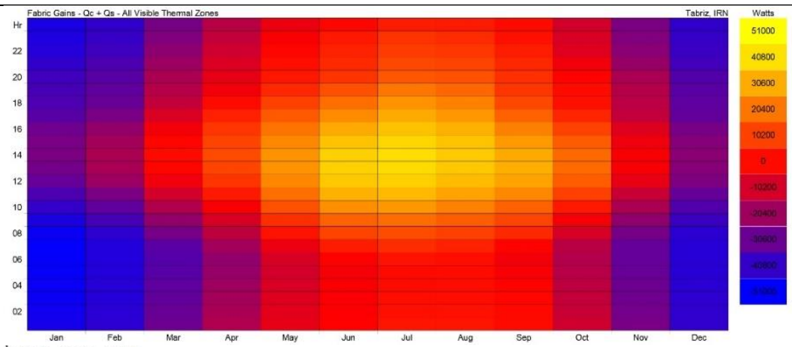
00	-47595	-43058	-30272	-17429	-6646	-1986	1347	1421	-525	-11637	-28286	-41814
01	-48395	-43525	-31378	-18729	-7610	-2539	415	649	-844	-12809	-29197	-42205
02	-49225	-44007	-32373	-19833	-8623	-3024	38	337	-1292	-13834	-30084	-42647
03	-49690	-43823	-33081	-20974	-9457	-3332	-150	96	-1899	-14788	-30488	-43089
04	-50329	-44659	-34519	-22675	-10928	-4061	-422	-261	-3690	-16346	-31476	-43614
05	-50726	-45025	-35224	-23114	-9571	-1686	1689	430	-4678	-17154	-31966	-43786
06	-50855	-45110	-33950	-19891	-5221	3735	6754	4498	-1562	-15531	-31972	-43893
07	-49235	-42168	-28171	-14031	1812	11612	13002	10635	6040	-9400	-28181	-42814
08	-45426	-37292	-22196	-8584	7636	17726	19473	16704	12177	-2892	-22796	-39448
09	-40615	-32011	-16090	-2457	14750	26936	28247	23999	17687	3709	-17216	-35077
10	-35802	-26531	-9446	3910	20122	33572	34588	30346	25129	11312	-11715	-30814
11	-30769	-20388	-3568	9118	24855	37729	39174	35120	30420	16702	-5254	-26395
12	-27970	-17702	-168	12222	27081	39390	41415	37747	32658	19267	-2494	-24450
13	-26804	-17643	876	12890	27084	39092	41767	38023	31752	19016	-2403	-24015
14	-27373	-19208	-587	11511	24668	36259	39979	36140	28328	15922	-4443	-25191
15	-29743	-22769	-3988	8453	20549	31263	36157	32514	23082	10714	-8294	-28132
16	-34373	-27521	-9092	4186	15287	24972	31288	27433	16833	4760	-14081	-32600
17	-36587	-31594	-13576	-286	10198	19099	26218	22645	11509	532	-15562	-33311
18	-37878	-32699	-16639	-4683	5218	13302	20682	17402	7935	-385	-16838	-34334
19	-39158	-34476	-18820	-6881	1945	7609	14116	13215	6445	-2052	-18725	-35684
20	-41843	-36695	-21615	-9322	284	5554	11332	10402	4937	-4804	-22308	-38640
21	-44286	-39376	-24221	-11689	-1490	4043	9098	7976	3199	-8440	-24996	-39980
22	-45638	-40656	-26856	-14124	-3286	2316	7194	5790	640	-9640	-26479	-41064
23	-46433	-41764	-28521	-15823	-5477	-1345	2840	2751	-203	-10909	-27716	-41804

B



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00	-47095	-42599	-29896	-17164	-6510	-1925	1402	1462	-499	-11428	-27944	-41379
01	-47890	-43086	-31008	-18464	-7458	-2474	444	668	-805	-12596	-28855	-41778
02	-48718	-43582	-32007	-19569	-8461	-2957	60	352	-1239	-13622	-29746	-42230
03	-49195	-43434	-32725	-20702	-9293	-3268	-134	111	-1834	-14580	-30170	-42677
04	-49831	-44251	-34129	-22359	-10729	-3981	-403	-237	-3555	-16103	-31141	-43200
05	-50237	-44600	-34832	-22873	-9638	-2062	1326	239	-4518	-16913	-31636	-43370
06	-50386	-44686	-33777	-19914	-5538	3149	6188	4072	-1842	-15611	-31665	-43478
07	-48972	-42077	-28329	-14415	1076	10588	12081	9867	5383	-9807	-28284	-42600
08	-45393	-37461	-22752	-9353	6524	16375	18219	15602	11069	-3730	-23193	-39440
09	-40852	-32506	-16994	-3537	13379	25379	26768	22641	16273	2504	-17943	-35322
10	-36286	-27309	-10590	2603	18570	31795	32844	28738	23532	9908	-12707	-31291
11	-31365	-21280	-4774	7747	23295	35905	37320	33384	28810	15296	-6289	-26992
12	-28548	-18580	-1330	10913	25613	37593	39573	36017	31131	17971	-3471	-25022
13	-27277	-18374	-131	11751	25772	37386	40008	36397	30396	17931	-3210	-24464
14	-27617	-19678	-1349	10632	23578	34752	38427	34730	27224	15127	-4960	-25389
15	-29710	-22931	-4453	7864	19752	30071	34917	31424	22272	10250	-8468	-28035
16	-34002	-27342	-9211	3889	14789	24120	30366	26684	16374	4678	-13820	-32136
17	-36006	-31112	-13383	-313	9980	18593	25635	22238	11395	809	-15115	-32782
18	-37258	-32184	-16245	-4464	5239	13121	20428	17336	8106	-118	-16370	-33788
19	-38559	-33960	-18396	-6619	2124	7795	14268	13379	6617	-1807	-18267	-35157
20	-41305	-36196	-21197	-9045	433	5716	11537	10598	5061	-4586	-21920	-38186
21	-43795	-38906	-23820	-11408	-1355	4199	9330	8170	3266	-8253	-24644	-39543
22	-45158	-40182	-26459	-13840	-3156	2453	7408	5956	676	-9434	-26129	-40629
23	-45943	-41296	-28133	-15546	-5361	-1279	2945	2838	-180	-10688	-27368	-41364

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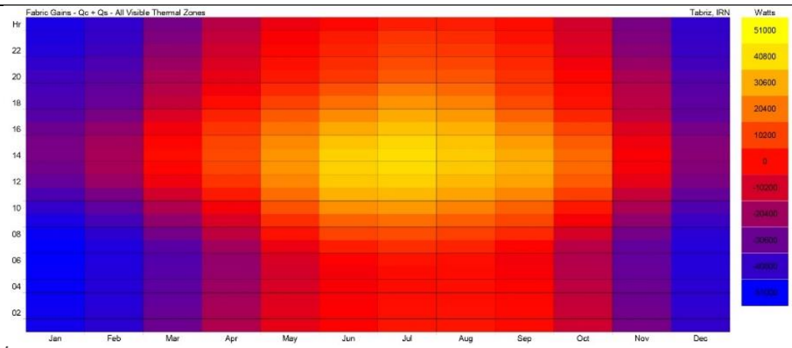
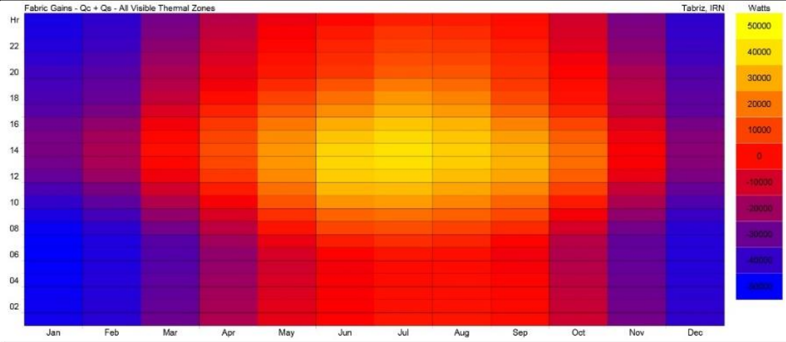


ANNUAL LOADS TABLE
Fabric Gains - Qc + Qs
All Visible Thermal Zones - Monthly Averages

HOUR	JAN (Wh)	FEB (Wh)	MAR (Wh)	APR (Wh)	MAY (Wh)	JUN (Wh)	JUL (Wh)	AUG (Wh)	SEP (Wh)	OCT (Wh)	NOV (Wh)	DEC (Wh)
00	-48221	-43611	-30548	-17484	-6593	-1927	1511	1557	-489	-11608	-28564	-42375
01	-49039	-44136	-31705	-18832	-7558	-2491	492	711	-792	-12812	-29507	-42797
02	-49894	-44666	-32745	-19977	-8586	-2990	86	381	-1227	-13874	-30434	-43274
03	-50401	-44552	-33498	-21140	-9445	-3315	-122	131	-1829	-14871	-30894	-43742
04	-51056	-45376	-34917	-22810	-10895	-4035	-397	-219	-3535	-16411	-31881	-44281
05	-51472	-45721	-35627	-23333	-9816	-2121	1329	258	-4497	-17232	-32385	-44452
06	-51649	-45808	-34604	-20410	-5753	3086	6197	4094	-1846	-15971	-32443	-44565
07	-50263	-43191	-29196	-14969	795	10502	12083	9879	5337	-10214	-29089	-43695
08	-46700	-38568	-23673	-9985	6182	16265	18214	15602	10955	-4201	-24016	-40543
09	-42187	-33652	-17981	-4245	12992	25281	26780	22632	16082	1964	-18810	-36445
10	-37647	-28495	-11604	1875	18234	31732	32879	28723	23313	9361	-13600	-32444
11	-32701	-22450	-5699	7154	23124	35946	37434	33452	28747	14867	-7125	-28136
12	-29813	-19661	-2047	10538	25683	37779	39808	36226	31294	17770	-4166	-26122
13	-28403	-19308	-638	11600	26055	37743	40399	36750	30738	17949	-3741	-25450
14	-28574	-20437	-1654	10693	24034	35274	38989	35235	27702	15342	-5308	-26227
15	-30494	-23518	-4590	8095	20327	30725	35639	32082	22852	10606	-8652	-28719
16	-34645	-27809	-9225	4224	15429	24867	31203	27467	17008	5094	-13899	-32714
17	-36580	-31545	-13343	59	10634	19384	26542	23098	12053	1238	-15139	-33313
18	-37816	-32639	-16207	-4125	5851	13904	21352	18216	8740	266	-16401	-34328
19	-39181	-34486	-18416	-6352	2644	8511	15172	14239	7178	-1522	-18373	-35764
20	-42065	-36836	-21337	-8886	821	6309	12363	11363	5490	-4435	-22178	-38934
21	-44740	-39688	-24117	-11377	-1107	4645	10050	8804	3537	-8261	-25083	-40435
22	-46201	-41069	-26898	-13934	-3040	2755	7990	6442	804	-9528	-26641	-41570
23	-47026	-42222	-28665	-15756	-5378	-1163	3304	3131	-134	-10806	-27931	-42339

D



ANNUAL LOADS TABLE
Fabric Gains - Qc + Qs
All Visible Thermal Zones - Monthly Averages

HOUR	JAN (Wh)	FEB (Wh)	MAR (Wh)	APR (Wh)	MAY (Wh)	JUN (Wh)	JUL (Wh)	AUG (Wh)	SEP (Wh)	OCT (Wh)	NOV (Wh)	DEC (Wh)
00	-46630	-42178	-29589	-16977	-6432	-1897	1403	1459	-490	-11297	-27659	-40972
01	-47418	-42665	-30693	-18268	-7369	-2441	447	666	-791	-12455	-28563	-41370
02	-48239	-43161	-31686	-19365	-8363	-2921	65	353	-1219	-13473	-29448	-41820
03	-48715	-43021	-32400	-20486	-9188	-3230	-130	113	-1806	-14425	-29873	-42265
04	-49346	-43828	-33788	-22123	-10606	-3934	-396	-230	-3500	-15929	-30833	-42783
05	-49751	-44171	-34484	-22629	-9510	-2012	1334	250	-4451	-16734	-31325	-42951
06	-49903	-44256	-33435	-19675	-5419	3194	6193	4082	-1779	-15440	-31359	-43059
07	-48501	-41649	-28016	-14206	1156	10618	12081	9869	5410	-9672	-27994	-42182
08	-44936	-37042	-22467	-9175	6578	16396	18214	15600	11075	-3625	-22922	-39026
09	-40412	-32099	-16735	-3385	13418	25395	26757	22636	16274	2583	-17692	-34918
10	-35876	-26929	-10349	2734	18606	31808	32823	28727	23538	9972	-12485	-30913
11	-30973	-20909	-4544	7864	23330	35914	37285	33358	28822	15361	-6077	-26629
12	-28167	-18218	-1107	11023	25649	37600	39526	35975	31143	18034	-3270	-24668
13	-26910	-18012	82	11860	25810	37384	39947	36339	30405	17992	-3021	-24118
14	-27254	-19315	-1141	10742	23616	34743	38356	34660	27225	15189	-4772	-25047
15	-29341	-22569	-4245	7974	19792	30057	34837	31346	22268	10314	-8277	-27689
16	-33606	-26975	-8993	4000	14832	24115	30277	26604	16367	4748	-13611	-31772
17	-35591	-30740	-13157	-198	10028	18592	25549	22161	11394	883	-14889	-32407
18	-36830	-31809	-16011	-4346	5289	13126	20349	17267	8109	-38	-16132	-33405
19	-38130	-33577	-18146	-6489	2176	7811	14226	13342	6627	-1726	-18023	-34770
20	-40875	-35805	-20934	-8901	483	5731	11518	10581	5066	-4497	-21668	-37799
21	-43359	-38510	-23548	-11253	-1305	4215	9323	8163	3266	-8152	-24383	-39150
22	-44714	-39776	-26174	-13675	-3101	2471	7404	5949	678	-9320	-25857	-40228
23	-45490	-40883	-27838	-15370	-5296	-1256	2943	2833	-174	-10561	-27087	-40957

E

Figure 9. Analysis of fabric gains data, four different modes

absorption and thermal performance. Different room and window configurations can lead to varying levels of energy gain or loss.

Mode B: High Energy Absorption: The analysis indicates that Mode B exhibits the highest energy absorption during the months of December to January, particularly between 12:00 and 14:00. These hours represent a peak period of energy absorption across all samples, with variations in the amount of energy absorption depending on the specific design mode.

Overall, these results suggest that the arrangement of rooms and windows has a substantial impact on energy absorption in the building. Mode B appears to excel in terms of energy absorption during specific times and months, emphasizing the importance of design choices in optimizing energy efficiency and thermal performance in the context of Tabriz city's climate.

Figure 9 clearly demonstrates that Mode B exhibits the highest absorption of solar energy and the lowest transmission of solar energy into the building during the months of December to January. This finding underscores the effectiveness of Mode B in capturing and utilizing solar energy for heating or other purposes, while also minimizing the amount of solar energy that escapes or penetrates the building during the coldest months of the year. This outcome suggests that Mode B is particularly well-suited for optimizing thermal performance and energy efficiency in the context of Tabriz city's cold climate during this specific time period.

Comparative analysis

Table 3 presents the analysis results for all types of building models and facilitates a comprehensive comparison among them. The goal is to identify the best model based on the criteria of minimum solar energy transmission and maximum solar energy absorption in the specific context of Tabriz's cold and dry climate. The research's primary objective is to determine the optimal building model that can achieve energy savings during the cold seasons. According to the analysis conducted using Ecotect, the key findings are as follows:

High Solar Absorption Leads to Lower Energy Consumption: The analysis underscores the importance of high solar absorption in reducing energy consumption, particularly during the cold winter months.

Mode B is the Best Model: Among the various building models considered, Mode B stands out as the best model. It exhibits the highest solar energy absorption and the lowest energy losses during the cold winter, making it the most energy-efficient option for Tabriz's climate.

Figure 10 provides visual representations of the plan and cross-section of the building in different floors for

Mode B, showcasing the design that has been identified as the most effective in terms of energy savings and thermal performance during cold seasons. This research contributes valuable insights into optimizing building design for energy efficiency in cold and dry climates.

Table 3. Comparative analysis of absorption and losses of solar energy for difference modes in residential buildings

Building models analysis	Time	Fabric Gains (Wh) July
	12	40631
Mode A	13	41028
	14	39294
	12	41415
Mode B	13	41767
	14	39979
	12	39573
Mode C	13	40008
	14	38427
	12	39808
Mode D	13	40399
	14	38989
	12	39526
Mode E	13	39947
	14	38356

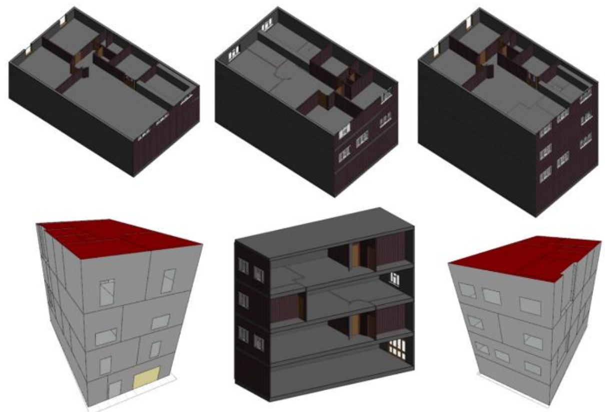


Figure 10. Optimum design of residential building for energy efficiency in Tabriz, mode B

CONCLUSION

With the rapid development of construction in Iran and the growing concern over gas energy shortages, the focus on energy-efficient and sustainable building development has intensified. This shift in focus not only aims to enhance the comfort of occupants but also seeks to reduce the gas energy consumption of buildings. Ecotect, with its capacity to visually and clearly analyze solar radiation, hourly solar exposure, fabric gains, and energy distribution within buildings, plays a crucial role in this endeavor.

This paper investigates the optimal building design in residential buildings, particularly tailored to the cold and dry climate of Tabriz. Given that many cities in Iran experience dry and cold winters, the energy consumption of residential buildings tends to be significantly high. The research in Tabriz, which faces a cold and dry climate, seeks to identify the most energy-efficient building design for cold seasons.

Based on the analyses conducted using Ecotect, the findings reveal that high solar absorption leads to lower energy consumption. Specifically, "Plan B" emerges as the optimal model, exhibiting maximum absorption and minimal energy losses during the cold winter months. The results demonstrate that the design of "Plan B" achieves the highest energy conservation in residential buildings, with fabric gains reaching 41,767 Wh. Additionally, "Plan A" shows notable energy conservation, with average fabric gains of 41,028 Wh during July, particularly between 12:00 to 14:00.

Furthermore, by utilizing simulation software, designers can proactively consider various ecological energy-efficiency methods during the early stages of design, contributing to more sustainable and energy-efficient building solutions.

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Persian Abstract

چکیده

هدف از این پژوهش تحلیل انرژی یک ساختمان مسکونی در شهر تبریز با اقلیم سرد و خشک با استفاده از شبیه‌سازی انرژی برای ارائه مدلی برای به حداقل رساندن مصرف انرژی است. مدل مقایسه‌ای تحلیل مصرف انرژی در یک واحد ساختمانی سه طبقه با ابعاد ۱۸۱ متر مربع با استفاده از ۵ حالت چیدمان در دیوار، کف، سقف، پنجره و در ارائه شده است. تعداد ۵ طرح با چیدمان اتاق‌ها و تعداد پنجره‌های مختلف از نظر صرفه‌جویی در مصرف انرژی در ۵۱ نمودار مختلف با هم مقایسه شد و طرح بهینه صرفه‌جویی در مصرف انرژی انتخاب شد. در مرحله بعد با توجه به نتایج به دست آمده به طراحی ساختمان در سایت مورد نظر پرداخته می‌شود. در پایان به منظور بررسی میزان جذب انرژی در ساختمان، نمودارهای انرژی برای منطقه حرارتی سردترین روز سال به دست می‌آید. نتایج نشان می‌دهد که بهینه‌ترین مصرف انرژی ساختمان مسکونی مربوط به طراحی پلان ب با مقدار بهره پارچه ۴۱۷۶۷ وات ساعت است. پس از آن، پلان طراحی شده الف، بهینه‌ترین مصرف انرژی را در ساختمان با مقدار بهره پارچه ۴۱۰۲۸ وات ساعت در ماه جولای نشان می‌دهد. نتایج این پژوهش برای بهره‌وری انرژی ساختمان‌های مسکونی و مدیریت زیست محیطی در آینده مفید است.