Providing sustainable energy consumption solutions based on behavioral patterns in a shared space using system dynamics methodology (Case Study: University of Tehran Student Dormitories)

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ABSTRACT

Objective: Changing energy consumption habits is fundamental to promoting sustainable development. This study simulates energy consumption patterns in shared spaces at the University of Tehran using a dynamic model, focusing on residents' behaviors to reduce electricity use and improve system efficiency.

Methods: To address the complex energy consumption system in student dormitories—shaped by behavioral, technical, environmental, and policy-related factors—a system dynamics approach was adopted. Experts in energy management and systems modeling contributed through collaborative meetings and interviews. Data were gathered from national institutions and questionnaires covering 2011–2021. Using Vensim DSS 6.4E, a dynamic model was built and simulated for 2021–2041. Sensitivity analysis helped identify effective energy management policies based on residents' behavior, and the model's outputs were analyzed to evaluate key variables.

Results: The model identified four key strategies for managing electricity consumption based on behavioral factors: management through economic investments in social awareness; management through residents' energy-saving behaviors; management through the actions and behaviors of dormitory staff and administrators; and management through increased investment in building infrastructure and equipment upgrades. Subsequently, the individual and combined implementation of each strategy was examined and compared in terms of their impact on the target variables. Ultimately, the combination of the first and third strategies was identified as the most effective approach to electricity consumption management, taking into account the behavioral patterns of the residents.

Conclusion: The study shows that combining economic investments with behavioral strategies is the most effective way to manage electricity consumption and improve environmental and social outcomes.

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Introduction

The increasing consumption of energy in the world leads to undesirable environmental and social problems such as carbon gas emissions, global warming, and the energy shortage crisis (Wang et al., 2019). According to forecasts, global energy consumption and carbon gas emissions will increase by approximately 33% (Sevena et al., 2020) and at an annual growth rate of 1.7% between 2010 and 2030 (Hu et al., 2021). Asian countries, responsible for approximately 53% of global carbon gas emissions (Ali et al., 2021), are projected to remain the largest energy consumers until 2040 (Golshahi et al., 2024). Iran, as part of the Asian countries, holds the second and third ranks in terms of natural gas reserves and petroleum product exports (Movahed et al., 2021). Iran, as part of the Asian countries, has experienced a significant surge in primary energy consumption despite holding the second and third ranks in terms of natural gas reserves and petroleum product exports (Movahed et al., 2021). The country's average annual energy consumption and intensity index are estimated to be more than 2.5 times the global average and 0.63%, respectively (Golshahi et al., 2024). Moreover, the country's energy consumption and carbon gas emissions have increased 6.2 and 6.1 times over the past six decades (Rahmani et al., 2020).

Therefore, given Iran's limited energy resources and the national approach to reducing oil dependency, decreasing energy consumption in various sectors, including industry and construction, has become a primary priority in energy-saving strategies (Ganjineh et al., 2024). In recent decades, the building sector has faced a sharp increase in energy demand due to population growth, rapid urbanization, and rising social needs. Approximately 40% of the world's electrical energy is consumed in buildings. Additionally, due to the close relationship between electricity generation and carbon dioxide (CO_2) emissions, buildings account for nearly 40% of total CO_2 emissions (Mathumitha et al., 2024).

Buildings are divided into two categories based on their function and efficiency: residential and commercial. While extensive studies have been conducted on energy consumption in residential buildings, research on non-residential (public) buildings, constituting a significant share of total energy consumption, remains limited (Kapur & Kaswan, 2020). Non-residential buildings (commercial and public) include various types such as educational institutions, restaurants, hotels, and hospitals, each serving different purposes and offering diverse services. Economic growth and population increase in these buildings have increased demand for healthcare, education, culture, and leisure services, raising energy consumption (Pérez-Lombard et al., 2008). Therefore, special attention to this sector and effective energy consumption management is significant (Heydarian et al., 2020). Educational buildings and student dormitories significantly contribute to energy consumption due to university expansion and the free access of residents to energy and other utilities (Jami et al., 2021).

Figures (1) and (2) illustrate the trend of electrical energy consumption in student dormitories at the University of Tehran and the university's electricity costs between 2011 and 2021. Given the increasing energy consumption trend, the university's expenses for electrical energy usage have risen steeply. Examining the behavior of students and other members of educational environments to reduce energy consumption is crucial, as educating students about sustainability and conservation can encourage them to help mitigate escalating environmental issues (Quevedo et al., 2024). Therefore, universities must establish strategies to promote and facilitate energy-saving behaviors among students and faculty members (Allen & Marquart-Pyatt, 2018). This research employs system dynamics modeling to design a dynamic model for identifying and analyzing energy reduction policies in shared spaces. The theoretical background is reviewed in Section 2, followed by the empirical background in Section 3. Section 4 presents the research methodology, and Section 5 discusses the analysis of findings. Section 6 offers conclusions and recommendations, while Section 7 compares the research results with previous studies.

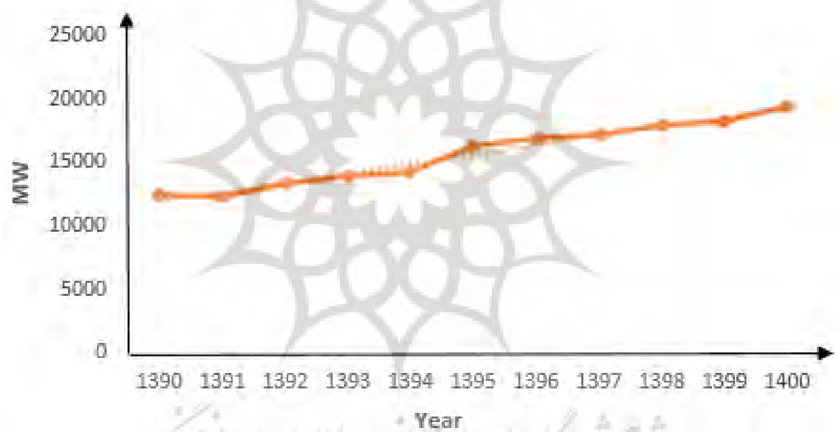


Figure 1. The Trend of Electrical Energy Consumption in Student Dormitories of the University of Tehran (2011–2021)

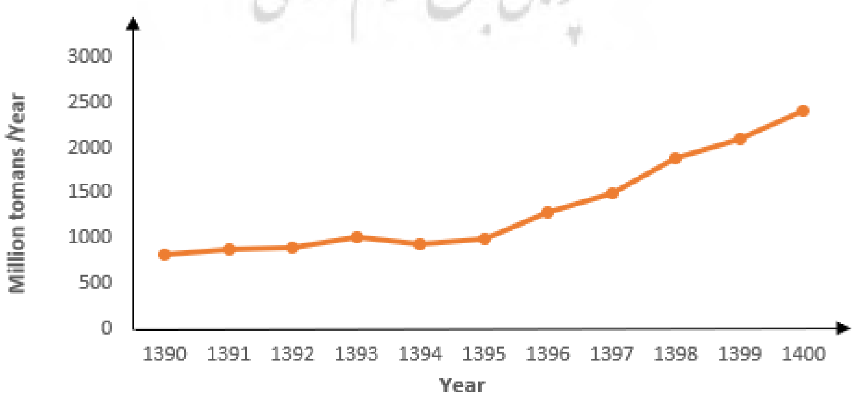


Figure 2. The Trend of University Electricity Expenditure (2011–2021)

Literature Background

Theoretical literature

Energy conservation is increasingly understood as a complex and multifaceted system wherein technical advancements and behavioral dimensions are deeply intertwined. The energy crises of the 1970s marked a pivotal shift in research focus toward behavioral and cultural aspects of energy use. This trajectory intensified in the 1990s as environmental concerns, particularly global warming and carbon emissions, underscored the importance of human attitudes in achieving sustainability goals. (Karatasou et al., 2014). Recent studies further emphasize that technological innovation, while necessary, remains insufficient to address contemporary energy challenges fully. Behavioral change is now recognized as a critical component for meeting climate targets, optimizing energy consumption, and improving long-term efficiency (Koasidis et al., 2022). In light of the review conducted through citation databases such as Scopus and academic search engines like Google Scholar and Semantic Scholar, and based on relevant literature (Heydarian et al., 2020; Liu et al., 2020; Yang et al., 2020), it was identified that the most frequently referenced theoretical frameworks in energy consumption research include the Theory of Reasoned Action, the Theory of Planned Behavior, the Norm Activation Model, the Value-Belief-Norm Theory, and the Attitude-Behavior-Context Model. However, due to the inherent limitations of each theory in capturing the complexities of human behavior, this study aims to adopt an integrated theoretical approach to investigate energy consumption better. A concise overview of each theory is presented below.

Theory of Reasoned Action and Theory of Planned Behavior (TPB)

TPB is a widely recognized framework for analyzing individual behavior and is an extension of the Theory of Reasoned Action, initially developed by Fishbein and Ajzen (1983). TPB posits that behavioral intention is the most immediate predictor of actual behavior and is shaped by three core constructs: attitude toward the behavior, which reflects the individual's evaluation of the expected outcomes (Ansu-Mensah & Bein, 2019); subjective norm, referring to the perceived social pressure to engage in or refrain from the behavior (Fu et al., 2021); and perceived behavioral control, denoting the individual's assessment of their ability to perform the behavior, influenced by prior experience, available resources, and external constraints (Ahmed Chemseddine & Kamel, 2021). These constructs provide a comprehensive framework for understanding and predicting behavioral patterns across diverse contexts (Kumar & Nayak, 2022).

Norm Activation Model (NAM)

NAM, initially proposed by Schwartz (1977). It is a widely recognized framework grounded in moral norms and designed to predict human behavior. Although initially developed within social psychology, NAM has been extensively applied to environmental research (Fang et al., 2019; Han et al., 2022). The model delineates a psychological mechanism through which internalized moral norms are activated and translated into pro-environmental actions. This process is driven by three interrelated constructs: personal norms, referring to internal moral obligations that compel individuals to engage in or refrain from specific behaviors; awareness of consequences (AC), which reflects an individual's recognition of the social and environmental implications of their actions or inactions (Arkorful, 2022); and Ascription of responsibility (AR) Ascription of responsibility (AR) denotes a sense of personal accountability for the adverse outcomes that may result from failing to engage in prosocial behavior. (Xuan et al., 2023).

Value–Belief–Norm Theory (VBN)

VBN Theory expands upon Norm Activation Theory by incorporating personal values, cognitive beliefs, and normative cues to explain pro-environmental behavior. It views environmental action as a product of individual value systems that influence personal norms and behavioral intentions (Al Mamun et al., 2022). Within this framework, values are classified into two primary dimensions: self-transcendence, which embodies concern for the environment and the welfare of others and is strongly associated with altruistic motivations; and self-enhancement, which emphasizes personal benefit, power, and success, typically driven by egoistic motivations (Han et al., 2017).

Motivation–Opportunity–Ability (MOA)

MacInnis et al. (1991) emphasize the central role of the MOA model in determining individuals' propensity to engage in particular behaviors, offering a structured framework for guiding and enhancing such actions (Ahmad et al., 2021). The model is built upon three foundational elements—motivation, opportunity, and ability—each of which plays a critical role in influencing behavioral outcomes across both personal (e.g., employees) and institutional (e.g., organizations or governments) contexts (Chai & Baudelaire, 2015). Motivation, driven by cognitive and neurological mechanisms, steers behavior toward goal-oriented outcomes. Opportunity encompasses external factors and situational conditions that prompt individuals to act. Ability refers to the mental and physical competencies required to perform a behavior or achieve a desired result successfully.

Numerous researchers have examined the relationship between energy consumption and consumer behavior. This section provides an overview of selected national and international studies and a summary of their findings.

Mahdavi et al. (2019) employed a systems dynamics framework to investigate strategies for improving energy efficiency in residential buildings. Their study emphasized technical interventions—such as LED lighting, HVAC enhancement, and insulation upgrades—alongside behavioral approaches, including public awareness initiatives. Jami Alahmadi et al. (2019) evaluated the effects of building retrofits on occupant comfort and energy efficiency through a comparative study of two dormitory buildings before and after refurbishment. Using questionnaires, on-site measurements, and dynamic simulation, their findings revealed that despite structural improvements, user satisfaction increased by only 4%, and energy performance showed negligible change. Moreover, post-retrofit dissatisfaction rose by 9.5% in the newer facility, highlighting potential limitations in retrofit effectiveness.

Ebrahimi et al. (2013) conducted a descriptive cross-sectional study examining water, electricity, and gas consumption in two student dormitories at Sabzevar University of Medical Sciences. Data were systematically collected across warm and cold seasons by recording meter readings, followed by statistical analysis using SPSS. The findings revealed that male dormitories' energy consumption per capita was higher than female dormitories. Moreover, overall student energy usage was lower than the national average, attributed to limited amenities and reduced access to energy-intensive resources. The study underscored the role of students' awareness and attitudes in promoting energy-efficient behaviors.

Li et al. (2024) explored university students' energy-saving behavior in a climatically diverse region of China using the Theory of Planned Behavior (TPB). Structural equation modeling showed that attitudes, social norms, and perceived behavioral control significantly shaped intentions, strongly predicting actual conservation practices—highlighting the value of targeted cognitive and normative interventions. Nadeem et al.(2023) examined university students' energy-saving behaviors in Pakistan by integrating the Stimulus-Organism-Response (SOR) model with the Theory of Planned Behavior (TPB). Their findings showed that media exposure and organizational climate influenced students' sense of responsibility and perceived social pressure, shaping their intentions and actual energy-saving actions, validating the predictive strength of the combined SOR–TPB framework.

Chen & Gou (2022) explored the gap between energy-saving intentions and behaviors among young residents in student dormitories. By extending the Theory of Planned Behavior (TPB) with Personal Moral Norms (PMNs) and applying structural equation modeling, they found that psychological factors—including attitudes, subjective norms, perceived behavioral control, and PMNs—significantly influenced intentions, predicting actual energy-saving behaviors. (Alomari et al., 2022) employed an extended Theory of Planned Behavior (TPB) model to analyze energy conservation behaviors among university faculty, students, and staff in Kuwait. PLS-SEM and multigroup analysis found that while TPB predictors were significant across all groups, their influence varied—faculty were more affected by environmental knowledge and awareness. In contrast, students responded more strongly to subjective norms. The study highlights the need for group-specific energy education strategies to foster sustainable behavior in academic settings. Xing et al. (2022) analyzed how building energy consumption information (BECI) influences college students' energy-saving intentions in China, using Social Cognitive Theory and the Theory of Planned Behavior. Their findings revealed that BECI impacts intention indirectly via two cognitive pathways: perceived benefit → perceived value → intention and perceived benefit & risk → personal norm → intention, with perceived benefit exerting the strongest influence. Wang & Zhang, (2022) used hierarchical linear modeling and an extended Theory of Planned Behavior (TPB) to assess how university energy-saving climate influences students' intentions and behaviors. Data from 661 students across 51 Chinese universities showed that attitudes, perceived responsibility, behavioral control, and subjective norms significantly predicted intention, the strongest driver of actual behavior. The study confirmed that organizational climate positively affects both intention and energy-saving behavior.

Du & Pan (2021) examined energy-saving behaviors in student dormitories using an expanded Theory of Planned Behavior (TPB) that included Personal Moral Norms (PMNs). Their results showed that PMNs, followed by perceived behavioral control and attitude, were the strongest predictors of intention, while subjective norms had little effect. Gender and thermal sensation moderated the link between intention and behavior. Zhu et al. (2021) studied how group-level factors affect individual energy-saving behaviors in shared residences. Using group dynamic theory and structural equation modeling, they found that descriptive norms and group interaction significantly influenced behavior, while self-transcendent group values had minimal impact. Obaidellah et al. (2019) conducted a pilot study in Malaysia's tropical climate using the Theory of Planned Behavior (TPB) to assess energy-saving intentions among university office occupants. Through structural equation modeling of survey data, they found that attitude and perception significantly influenced behavioral intention, with participants showing moderate engagement in equipment use and energy-saving practices. Brinkhurst et al. (2016) found that a three-week energy-saving competition in college dorms led to a 6.4% reduction in electricity use and increased pro-environmental behaviors. These changes were linked to stronger group identification and perceived social norms, highlighting the impact of social incentives and real-time feedback. Karp et al. (2016) showed that adding ambient, group-level energy feedback to conservation tips and goal-setting in dormitories led to significantly greater electricity savings. The study highlights the power of real-time visual feedback in reinforcing social norms and promoting sustainable behavior.

A comprehensive assessment of prior research underscores the fundamental significance of behavioral and psychological variables in shaping energy consumption and conservation patterns. Existing literature predominantly adopts descriptive-analytical methodologies, often assuming linear interrelations among variables. These assumptions have rarely been scrutinized within dynamic and systemic frameworks that reflect particular economic, political, and cultural conditions—especially within contexts where energy is freely accessible to residents. This study aims to address these gaps by applying an integrated behavioral framework to identify key behavioral determinants and develop actionable policy interventions to curb energy use in such socio-technical environments.

Materials and Methods

This research methodology integrates descriptive and analytical approaches tailored to the multifaceted nature of the study. Initially, a descriptive strategy is employed to investigate theoretical constructs and existing literature, offering insight into current conditions, identified gaps, and conceptual uncertainties surrounding the research issue. Subsequently, a systematic analytical approach is utilized to examine the evolving dynamics of behavioral and psychological determinants impacting electricity consumption and their interactions with structural building parameters.

Causal relationships among variables are investigated using the system dynamics framework, modeled according to Forrester's approach (1994), through the following stages:

- Stage 1: Problem Identification and Definition — Structuring the research problem with precision
- Stage 2: Causal Loop Modeling — Articulating dynamic interdependencies and hypotheses
- Stage 3: Stock-and-Flow Construction — Employing survey data to map behavioral variables mathematically; regression coefficients were derived from weighted responses collected among Tehran University dormitory residents
- Stage 4: Simulation and Model Validation — Executed in Vensim software using time-series datasets spanning 2011–2021
- Stage 5: Policy Formulation and Deployment

The data were collected from institutional records and in collaboration with planning divisions of the University of Tehran, Tehran's Dormitory Authority, Tehran Electricity Distribution Company, the Iranian Statistical Center, Tehran Meteorological Organization, and direct surveys conducted with students. The simulation model was developed using Vensim software based on time-series data from 2011 to 2021 and projected over a 20-year horizon (2021–2041).

Results

In alignment with the stages of system dynamics modeling, a simulation framework was designed to explore the influence of psychological variables on electricity consumption among students residing in the University of Tehran dormitories. These facilities comprise four centralized housing complexes and 25 distributed units, amounting to 57 dormitories and 54 auxiliary non-residential buildings throughout Tehran. Given the extensive infrastructure and substantial energy demands, rigorous analysis of usage patterns is imperative. A primary behavioral determinant is the lack of direct cost associated with energy usage, which may reduce consumption awareness and foster inefficient behavioral patterns. Conversely, strategic interventions to increase energy-related awareness and employ psychological incentives can yield measurable improvements in conservation behavior. Additional factors—including the technical efficiency of appliances and the operational role of dormitory administrators—have a marked impact on overall consumption levels. Moreover, integrating advanced technologies and intelligent energy management systems holds considerable promise in reducing energy waste and improving performance outcomes. Consequently, targeted policy design, educational outreach, and monitoring initiatives implemented by dormitory personnel can play a vital role in achieving energy optimization across the residential system.

Structuring the Problem

The investigation commenced with a thorough literature review on psychological determinants and reference behaviors relevant to residential energy consumption patterns. Following thematic analysis of electricity usage and its upward trend, the problem was systematically structured through expert consultations—including professionals in energy governance, systems thinking, and dynamic modeling—utilizing collaborative workshops and semi-structured interviews. In alignment with the conceptual framework and dynamic hypotheses, the research delineated five key subsystems: (1) behavioral patterns of residents, (2) behavioral influences of administrators, (3) electricity consumption mechanisms, (4) financial resource allocations, and (5) incentivizing factors contributing to increased electricity usage. Each subsystem's elements were mapped, interrelated, and bounded to define the system's scope. Their structure and interdependencies are illustrated in Figure 3, followed by an analytical exploration of each subsystem's function and relevance.

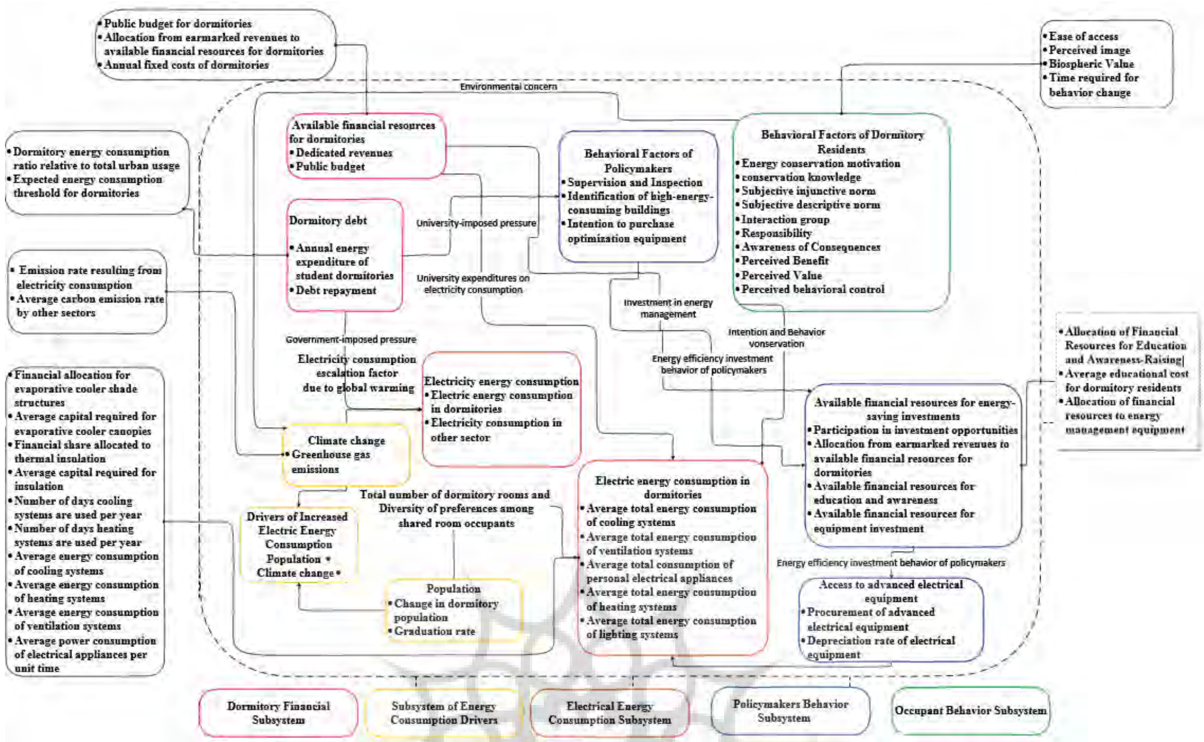


Figure 3. Subsystem model for analyzing the electricity consumption trends of dormitories based on residents' behavioral patterns

Behavioral Factors Subsystem of Residents: Resident Behavioral Framework. The behavioral subsystem encapsulates critical behavioral indicators identified through empirical inquiry, mapping the dynamics and causal links among influencing factors. These behaviors evolve in response to external pressures exerted by the administrators' behavioral subsystem, dormitory-level financial mechanisms, and consumption-enhancing stimuli. The resulting interplay modifies residents' behavioral trajectories regarding electricity usage, shaping energy-saving tendencies. This subsystem connects to the electricity consumption domain via residents' adaptive responses, which directly mediate overall energy demand.

Electricity Consumption Subsystem : The Electricity Consumption Subsystem comprises two main sectors: electricity usage within dormitories and other organizational units. Dormitory electricity consumption includes the operation of cooling, heating, lighting, and ventilation systems, as well as the use of personal electrical devices. This energy usage is financially connected to the financial subsystem through the costs incurred by electricity consumption. Moreover, dormitory consumption accounts for a portion of Tehran's electricity usage and contributes to power shortages. Consequently, increased electricity demand exerts governmental pressure through raised tariffs, leading to financial liabilities and affecting the dormitory's fiscal sustainability.

Dormitory Financial Subsystem: This subsystem consists of financial resources available to the dormitories and dormitory debt. The financial resources available to the dormitories are provided through dedicated revenues and the university's general budget. The debt section includes part of the annual energy consumption costs of the dormitories that remain unpaid and have accumulated as debt. The accumulation of debt creates pressure from the university, leading to monitoring and inspections, identifying high-consumption buildings, and the administrators' intention to purchase equipment for consumption optimization. In this way, this subsystem influences the behavioral subsystem of the administrators. On the other hand, a portion of the financial resources available to the dormitories is invested in energy consumption management, which also links this subsystem to the financial resources available for energy-saving investments related to the behavioral subsystem of the administrators.

Behavioral Factors Subsystem of Administrators: The Behavioral Factors of Administrators include supervision and inspection, identification of high-consumption buildings, and the intention to purchase optimization equipment. On the other hand, the financial resources available for investment in energy-saving initiatives consist of the portion of the dormitory's accessible budget allocated to energy management and the extent of participation in investment opportunities supported by the Welfare Fund to assist in energy management. Therefore, since the administrators determine the number of financial resources allocated for energy-saving investments, it is considered part of the behavioral factors' subsystem of the administrators. The administrators' investment behavior in energy optimization determines how the available financial resources for energy-saving investments are managed and allocated—for instance, towards education and awareness programs, procurement of consumption optimization equipment (such as air-conditioner shades and insulation), and the purchase of advanced technologies. Accordingly, this subsystem connects with the Electricity Consumption Subsystem through the availability and use of advanced electrical equipment and the impact of such technologies on reducing electricity consumption. Moreover, this subsystem also interacts with the Behavioral Factors of Residents through investments in educational programs and promotional activities to increase the number of trained students and influence their behavioral patterns. This, in turn, affects the electricity consumption subsystem through the energy-saving behaviors of the residents. Additionally, administrators' behavioral factors influence dormitory residents' behavioral patterns through supervision, inspection, and enforcement of regulations, by establishing prescriptive norms. Consequently, this channel also links the behavioral factors subsystem of administrators with the behavioral factors of residents and ultimately with the electricity consumption subsystem.

Subsystem of Drivers Increasing Electrical Energy Consumption: Population and climate change, recognized as drivers of rising electricity consumption, are considered subsystems within the energy consumption framework. Population growth leads to increased demand and electricity usage. In dormitory settings, the rise in resident numbers and evolving preferences—particularly for shared room arrangements—connect this subsystem directly with the Electricity Consumption Subsystem. On the other hand, climate change, particularly global warming, contributes to increased electricity consumption, again linking this driver subsystem to the electricity consumption subsystem. From another perspective, climate change and growing environmental concerns influence humanitarian values and interact with the Behavioral Factors Subsystem. This behavioral impact on residents indirectly affects the electricity consumption subsystem as well.

It is noteworthy that the endogenous and exogenous variables of the model are as follows:

Endogenous variables include: perceived behavioral control, energy-saving motivation, energy-saving opportunity, satisfaction with responsible consumption, ease of access, awareness of consequences, environmental concern, moral norms, prescriptive norms, responsibility, change in energy-saving intention, energy-saving attitude, perceived value, perceived benefits, energy-saving behavior, daily hours of cooling system use, daily hours of personal electrical equipment use, insulation (double glazing), dormitory electricity consumption, diversity of preferences among shared-room residents, climatic and cultural diversity of students, population per room, greenhouse gas emissions, climate change, dormitory public budget, university's dedicated revenues, other expenses, university's payments for electricity consumption, investment in energy management, participation in investment opportunities, energy-saving intention, time required for behavior change, group interaction, energy-saving knowledge, ratio of trained residents to dormitory population, advertising, trained students, participation rate in energy-saving investment opportunities, shading of evaporative coolers, average total consumption of cooling systems, average total consumption of heating systems, average total consumption of ventilation systems, average total consumption of personal electrical devices, daily hours of heating system use, ventilation, and lighting, allocation of financial resources to optimization investment behavior, financial resources available for education and outreach, financial resources available for equipment investment, financial resources available to dormitories, financial resources available for energy-saving investments, debt repayment, annual energy costs of dormitory consumption, dormitory debt, dormitory population, purchase of advanced electrical equipment, access to advanced electrical equipment, and energy-saving intention of dormitory residents.

Exogenous variables include: emission rate from electricity consumption, average carbon emission rate from other sectors, biosphere value, perceived image of dormitory residents' responsible behavior, support from senior managers for responsible consumption, time required for behavior change, allocation of financial resources to energy-saving advertising, to energy management equipment, and to education and awareness, ease of access, regional electricity payment ratio, electricity consumption in other sectors, average capital required for electrical equipment, participation in energy-saving investment opportunities, allocation of dedicated revenues to available resources, dedicated revenues, financial credit from public budget, annual fixed costs of dormitories, average ventilation system consumption, heating system consumption, electrical equipment consumption per time unit, cooling system consumption, average study duration, total number of dormitory rooms, expected electricity consumption threshold of dormitories, share of advanced equipment in available financial resources, average equipment lifecycle, average hourly lighting system consumption, average cost of resident training, ratio of trained residents to dormitory population, average cooling system consumption, average capital required for evaporative cooler shading, number of days heating systems are used per year, number of days cooling systems are used per year, average study duration, student admission rate, and adjustment of climatic and cultural diversity.

Dynamic Hypothesis and Causal Loop Diagram:

Literature review, prior studies, and insights from planners, decision-makers, and experts from relevant departments have been utilized to identify causal relationships within the system. Initially, the dynamic hypothesis diagram was drawn, followed by a causal loop diagram to examine the factors influencing dormitory electricity consumption, considering residents' behavioral patterns. This analysis illustrates the feedback relationships among these variables (Figures 4 and 5). Key feedback loops representing the model's primary dynamic hypotheses are introduced and analyzed to deepen understanding of the system structure.

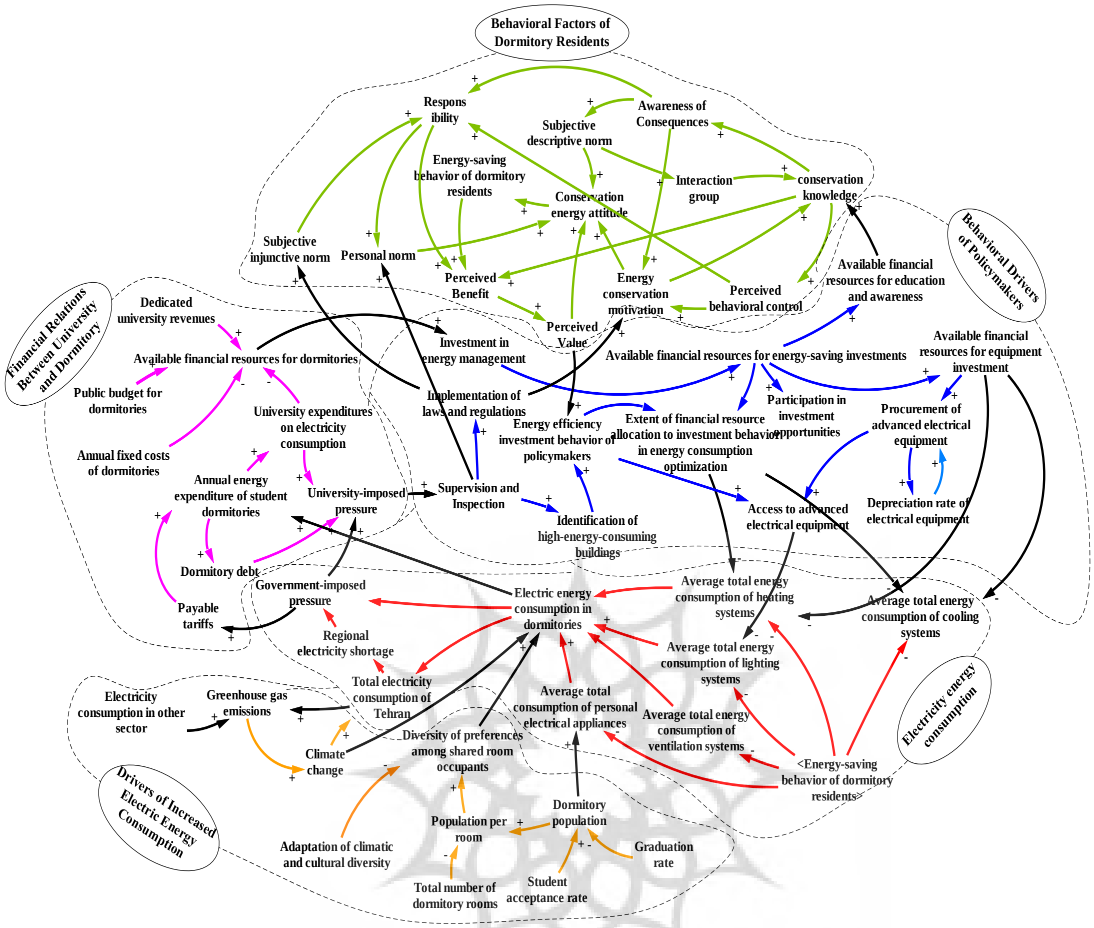


Figure 4. Diagram of the system's dynamic hypotheses for analyzing electricity consumption trends in Tehran University dormitories based on residents' behavioral patterns.

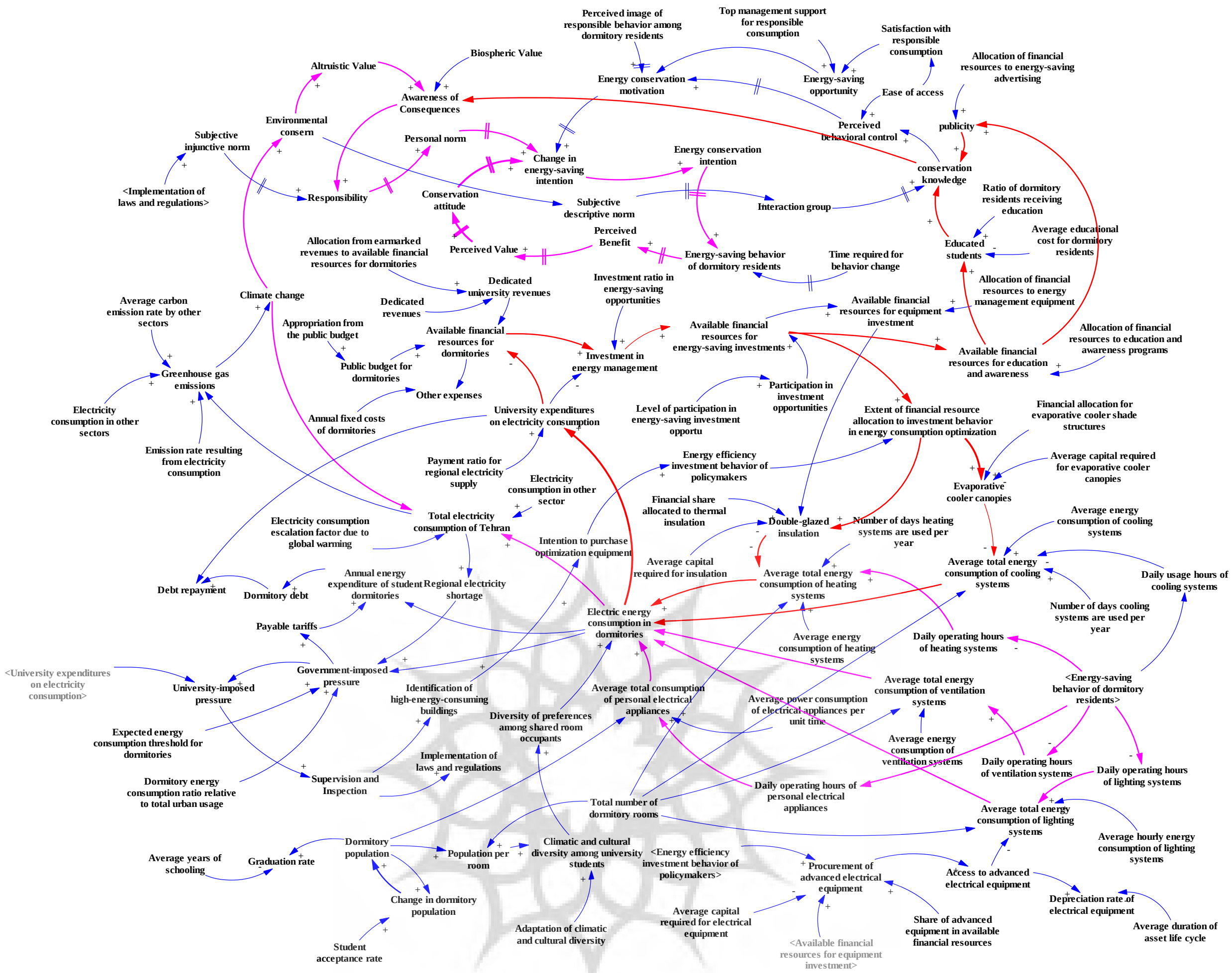


Figure 5. Causal Loop Diagram of the System – Analyzing the Trend of Electrical Energy Consumption in Tehran University Dormitories Based on Residents' Behavioral Patterns

Introduction of Selected Causal Loops in the Model

Reinforcing and Balancing Loops of Electrical Energy Consumption in Dormitories: If electricity consumption in dormitories increases, the university's energy payment expenses will also rise. As these costs escalate, the financial resources available to dormitories diminish, leading to reduced investment in energy management. Consequently, the funds available for energy-saving initiatives decline, and the budget allocated for optimization-focused investment behaviors contracts. As a result, purchases of equipment such as evaporative cooler shades, insulation materials, and other energy efficiency-related tools decrease, which increases energy waste and raises the average usage of heating and cooling systems. Ultimately, this exerts upward pressure on total electricity consumption in dormitories, reinforcing the system's demand growth (Figure 6

– Reinforcing Loop, marked with a positive sign). On the other hand, as electricity consumption rises, the annual energy costs of dormitories also increase, which heightens the accumulation of debt. Growing debt triggers pressure from the university, resulting in intensified oversight and inspection. Regulatory enforcement is pursued rigorously in response to increased supervision, and normative controls intensify. These norms contribute to greater accountability among residents and foster a shared moral standard, strengthening their intention to conserve energy. With these conservation-oriented behaviors—such as reduced usage hours of cooling/heating/lighting systems and personal electrical devices—the average consumption across systems declines, leading to a moderated reduction in the total electricity consumption of dormitories (Figure 3 – Balancing Loop, marked with a negative sign).

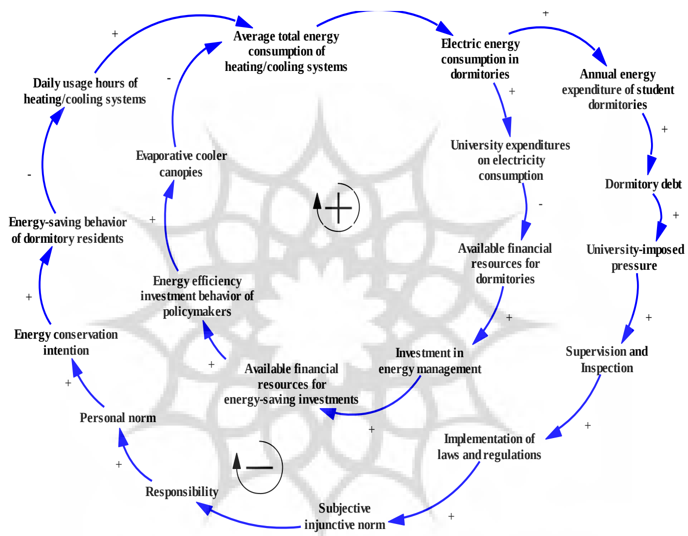


Figure 6. Reinforcing and Balancing Feedback Loops of Electricity Consumption in Dormitories

These feedback loops encompass positive and negative relationships, reinforcing or weakening a given variable. Accordingly, based on the proposed dynamic hypothesis derived from the constructed feedback loops for electricity consumption in dormitories, the emergence of undesirable behavior and an upward trend in energy use indicate the dominance of the reinforcing (positive) feedback loop over the balancing (negative) one. To guide electricity consumption behavior toward desired outcomes and reduce energy use, activating the balancing loop and ensuring its dominance over the reinforcing loop is essential. Therefore, the balancing loop can overtake the reinforcing loop through appropriate policy interventions outlined in the subsequent modeling process, and by specifying the required changes in leverage variables. This enables a decline in consumption even in the face of rising demand. Furthermore, a positive feedback loop can later strengthen such a reduction. The objective is to establish a balance between reinforcing and balancing loops—a dynamic equilibrium that supports system stability and prevents excessive fluctuations.

Reinforcing and Balancing Loops of Residents' Energy-Saving Behavior: As illustrated in Figure 7, an increase in residents' energy-saving behavior leads to a reduction in the number of hours they use cooling, heating, lighting systems, and personal electrical devices. Consequently, the average consumption of these systems decreases, resulting in lower total electricity usage within the dormitories. As consumption declines, the university's electricity expenditures are reduced, which increases the financial resources available to dormitories. With more accessible funding, the potential for investment in energy management rises. This increased availability of resources facilitates further investment in energy-saving initiatives, positively impacting the resources allocated for education and awareness programs. As a result, the number of trained students and the extent of promotional efforts grow, improving energy-saving knowledge. This enhanced knowledge fosters greater awareness of consequences, strengthening residents' sense of responsibility and moral norms, ultimately increasing their intention to conserve energy and reinforcing energy-saving behaviors (reinforcing loop – positive sign). Another reinforcing loop also emerges: as energy-saving behaviors increase, residents perceive more benefits, enhancing conservation's perceived value. This elevated value positively influences attitudes toward saving energy. As attitudes strengthen, the intention to conserve rises again, reinforcing energy-saving behavior (reinforcing loop – positive sign). On the other hand, if energy-saving behaviors decline, the usage hours of cooling, heating, lighting systems, and personal devices increase, leading to higher electricity consumption in dormitories. This increase contributes to higher total electricity consumption across Tehran, exacerbating greenhouse gas emissions and accelerating climate change. These environmental changes intensify concern and humanitarian values, enhancing awareness of consequences, individual responsibility, and ethical norms. Thus, the intention to conserve energy rises, and a balancing loop is activated that helps to compensate for and counteract the prior behavioral decline—ultimately contributing to a moderated increase in energy-saving behavior (balancing loop – negative sign).

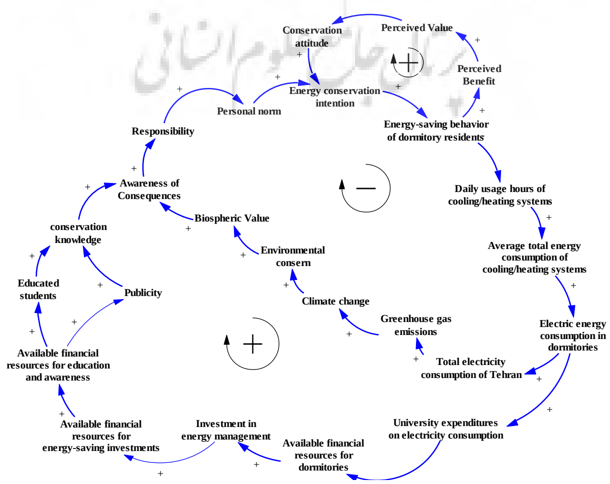


Figure 7. Reinforcing and Balancing Loops of Residents' Energy-Saving Behavior

Balancing Loop of Access to Advanced Equipment: Access to advanced equipment is influenced by two key factors: the rate of equipment acquisition and the expiration rate of existing devices. There is an inverse relationship between equipment access and the expiration rate, and a direct relationship with the volume of new purchases. In other words, decreased access to equipment corresponds with a higher rate of outdated devices, whereas increased purchasing activity enhances access to advanced technologies. According to Figure 8, reduced access to electrical equipment leads to increased electricity consumption in dormitories. This rise in energy demand escalates pressure from governmental authorities, followed by intensified scrutiny from the university. As institutional pressure grows, oversight and inspection efforts expand, resulting in the identification of high-consumption buildings. Consequently, participation in energy-saving initiatives increases, leading to greater availability of financial resources for efficiency-focused investments. This financial improvement also expands the capital available for upgrading equipment, stimulating the acquisition of advanced electrical devices. As more modern equipment is purchased, access to high-efficiency technologies improves in a regulated and progressive manner—establishing a balancing feedback loop that counteracts initial limitations.

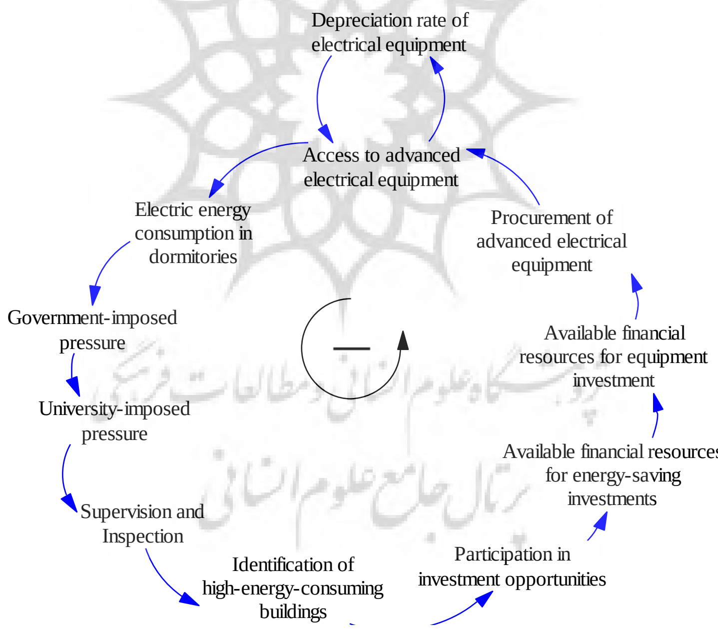


Figure 8. Balancing Loop of Access to Advanced Electrical Equipment

Stock and Flow Diagram

To model the structures and flow dynamics, in addition to the variables identified in the causal diagram, new variables and parameters must be defined to facilitate the mathematical calculation of relationships. For constructing the flow model, insights from in-depth interviews with research participants and quantitative data from stakeholders between 2011 and 2021 were used to structure the problem model. Figure 9 illustrates the stock and flow diagram regarding electricity consumption trends in dormitories, based on residents' behavioral patterns. Subsequently, the values of the model’s stock variables and some core mathematical relationships are presented in Tables 1 and 2, respectively.

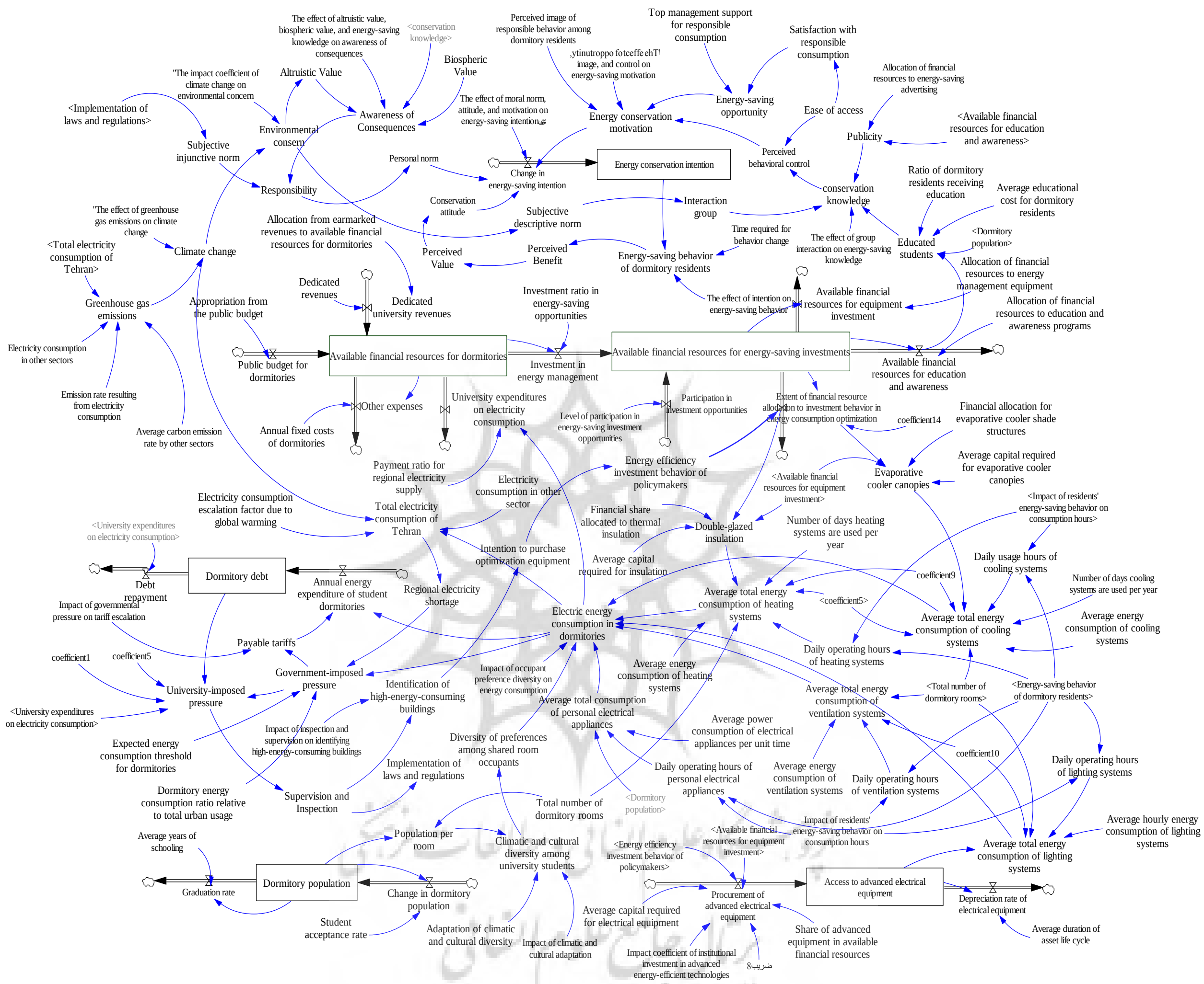


Figure 9. Stock and Flow Diagram of the Electrical Energy Consumption System in Tehran University Dormitories Based on Residents’ Behavioral Patterns

Table 1. Baseline-Year Values of the Model's Stock Variables and Their Units of Measurement

Stock Variable	Value	Unit	Stock Variable	Value	Unit
Dormitory Debt	1076.48	Million Tomans	Financial Resources for Energy-Saving Investment	2213.45	Million Tomans
Residents' Intention to Conserve Energy	4.152	Dmnl	Access to Advanced Electrical Equipment	23	Count
Dormitory Population	10,594	Persons	Financial Resources Available to Dormitories	3212.18	Million Tomans

Table 2. Selected Mathematical Relationships between Variables in the System Dynamics Model of Electrical Energy Consumption in Tehran University Dormitories Based on Residents' Behavioral Patterns

Variables	Mathematical and logical relationship	Units
Awareness of Consequences	((0.09*Biospheric Value) +(0.12*Altruistic Value) +(0.79*conservation knowledge)) *"The effect of altruistic value, biospheric value, and energy-saving knowledge on awareness of consequences"	Dmnl
Altruistic Value	1.878+(Environmental concern *0.567)	Dmnl
Greenhouse gas emissions	(Average carbon emission rate by other sectors*Electricity consumption in other sectors) + (Total electricity consumption of Tehran*Emission rate resulting from electricity consumption)	million ton
Energy conservation motivation	((Perceived behavioral control*0.078) + ("Energy-saving opportunity"*0.234) + (Perceived image of responsible behavior among dormitory residents *0.352) +1.44) *"The effect of opportunity, image, and control on energy-saving motivation"	Dmnl
Dormitory debt	MAX (Annual energy expenditure of student dormitories-Debt repayment, 0)	million toman
Publicity	1.3953*Available financial resources for education and awareness*"Allocation to energy-saving advertising"	Dmnl
Interaction group	(0.446*Subjective descriptive norm) +1.699	Dmnl
Change in dormitory population	Dormitory population*Student acceptance rate	person/year
Change in energy-saving intention.	(-0.016+(Energy conservation motivation*0.172) +(Conservation attitude*0.252) +(Personal norm*0.559) *"The effect of moral norm, attitude, and motivation on energy-saving intention " *100	Dmnl/year
Climatic and cultural diversity among university students	(Population per room/Adaptation of climatic and cultural diversity) *Impact of climatic and cultural adaptation	Dmnl
Dormitory population	Change in dormitory population-Graduation rate	person
conservation knowledge	(0.22375* Publicity) +(Educated students*0.4265*"The effect of group interaction on energy-saving knowledge") +(0.34975*Interaction group)	Dmnl
Educated students	MIN (Available financial resources for education and awareness/Average educational cost for dormitory residents , Dormitory population*Ratio of dormitory residents receiving education)	person/year

Variables	Mathematical and logical relationship	Units
Dedicated university revenues	Dedicated revenues*Allocation from earmarked revenues to available financial resources for dormitories	million toman/year
Access to advanced electrical equipment	(Procurement of advanced electrical equipment-Expired rate)	number
Energy-saving behavior of dormitory residents	(Energy conservation intention)/Time required for behavior change *"The effect of intention on energy-saving behavior"	Dmnl
Evaporative cooler canopies	((Allocation rate to investment behavior optimization +Available financial resources for equipment investment *Financial allocation for evaporative cooler shade structures/Average capital required for evaporative cooler canopies	number/year
Identification of high-energy-consuming buildings	Supervision and Inspection*"Impact of inspection and supervision on identifying high-energy-consuming buildings"	Dmnl
Double-glazed insulation	((Available financial resources for equipment investment +Allocation rate to investment behavior optimization *Financial share allocated to thermal insulation)/Average capital required for insulation	number/year
Energy-saving opportunity	(0.211*Top management support for responsible consumption) + (0.286*Satisfaction with responsible consumption) +2.223	Dmnl
Intention to purchase optimization equipment	"Identification of high-energy-consuming buildings"*1.0902	Dmnl
Average total energy consumption of ventilation systems	Average energy consumption of ventilation systems*Daily operating hours of ventilation systems*Total number of dormitory rooms *coefficient10	M W
Average total energy consumption of lighting systems	Daily operating hours of lighting systems*Average hourly energy consumption of lighting systems*((Total number of dormitory rooms)- (0.45*Access to advanced electrical equipment)) * coefficient10	M W
Average total energy consumption of cooling systems	Daily usage hours of cooling systems*Number of days cooling systems are used per year*Average energy consumption of cooling systems*((Total number of dormitory rooms*coefficient5) - (0.3*Evaporative cooler canopies)) *coefficient9*0.01	M W
Average total energy consumption of heating systems	Daily operating hours of heating systems*Number of days heating systems are used per year*Average energy consumption of heating systems*((Total number of dormitory rooms*coefficient5) - (0.4*"Double-glazed insulation")) *coefficient9*0.001	M W
Average total consumption of personal electrical appliances	Average power consumption of electrical appliances per unit time*Daily operating hours of personal electrical appliances *Dormitory population*0.01	M W
Perceived Benefit	3.476+("Energy-saving behavior of dormitory residents"*227)	Dmnl
Perceived Value	(0.591*Perceived Benefit) +1.776	Dmnl
Electric energy consumption in dormitories	((1+Diversity of preferences among shared room occupants*Impact of occupant preference diversity on energy consumption) *(Average total energy consumption of ventilation systems +Average total energy consumption of lighting systems +Average total energy consumption of cooling systems +Average total energy consumption of heating systems +Average total consumption of personal electrical appliances))	M W

Variables	Mathematical and logical relationship	Units
Available financial resources for education and awareness	"Available financial resources for energy-saving investments"*Allocation to education and awareness programs	million toman/year
Conservation attitude	3.519+(Perceived Value*0.213)	Dmnl
Annual energy expenditure of student dormitories	Payable tariffs*Electric energy consumption in dormitories	million toman/year
Personal norm	(Responsibility*0.679) +1.35	Dmnl
Subjective injunctive norm	2.954+(Implementation of laws and regulations*0.425)	Dmnl
Subjective descriptive norm	(329*Environmental concern) + 2.266	Dmnl
Available financial resources for dormitories	MAX ((Public budget for dormitories + Dedicated university revenues-Other expenses -Investment in energy management-University expenditures on electricity consumption), 0)	million toman
Available financial resources for equipment investment	"Available financial resources for energy-saving investments"*"\"Allocation to energy management equipment"	million toman/year

The logical and mathematical relationships of the model are defined based on principles of system dynamics. Regarding qualitative variables and behavioral factors, questionnaires were distributed among the residents of dormitories at the University of Tehran. Based on weighting, mean calculation, and determination of regression coefficients between causal variables, the degree of variation in qualitative variables related to behavioral factors has been estimated.

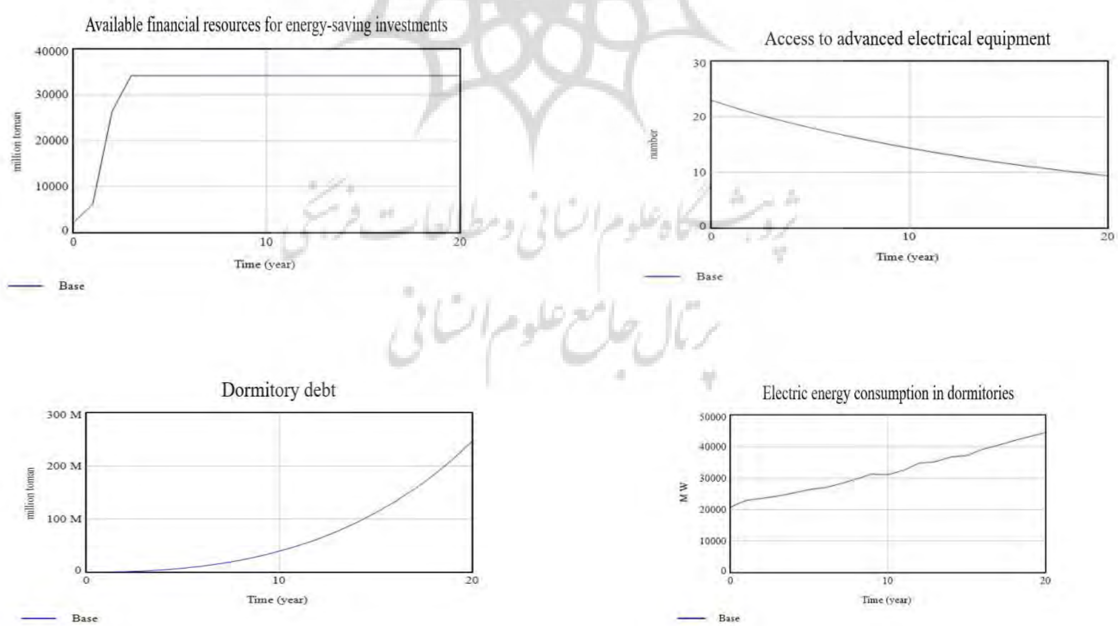
Model Simulation and Validation

For validation, in addition to confirming the boundary adequacy test and aligning the model structure with descriptive knowledge, expert evaluations were conducted based on reliability, transferability, and dependability criteria. Furthermore, structural and behavioral validation tests—including goodness-of-fit tests, extreme condition testing, parameter confirmation, parameter sensitivity analysis, dimensional consistency, aggregate bias error assessment, and behavior reproduction—were performed using the Root Mean Square Percentage Error (RMSPE) index. Table 3 presents the results of the behavior reproduction test for selected model variables.

Table 3. RMSPE Index Calculation

Population (Number of People)		University expenditures on electricity consumption (Million Tomans/Year)		Participation in investment (Million opportunities Tomans/Year)		Electrical Energy Consumption (Megawatts)		Model Variable
Simulated Value	Actual Value	Simulated Value	Actual Value	Simulated Value	Actual Value	Simulated Value	Actual Value	
9009.01	9015	846.354	809.9313	931.499	800	12496	12496	1390
9389.74	9201	869.527	881.3788	1012.41	1058	12838.1	12368	1391
9682.58	9428	916.351	895.4325	1204.4	1216.7	13529.5	13369	1392
9742.51	9501	987.729	1007.6141	1419.1	1399.205	14583.3	13885	1393
9911.23	9946	1003.9	928.019	1658.97	1609.08575	16003.3	14225	1394
10015.23	9606	1205.5	992.2991	1926.76	1850.4486	17798.7	16377	1395
9606.28	9455	1353.27	1277.8506	2225.5	2128.0159	18980.3	16885	1396
9835.78	9508	1527.9	1500.3215	2558.52	2447.2182	19558.8	17200	1397
9938.12	9758	1897.8	1885.6045	2929.54	2814.3010	20147.7	17997	1398
10021.08	9963	2168.69	2100.6385	3342.65	3236.4461	21551.4	18224	1399
10106.74	10096	2500.21	2412.0213	3802.39	4000	22128	19377	1400
0/022		0/075		0/061		0/108		RSMPE

After completing validation procedures, an initial simulation was performed over a 20-year time horizon. Figure 10 illustrates the trajectories of key stock-and-flow variables whose dynamic behavior is essential for evaluating the system's overall performance.



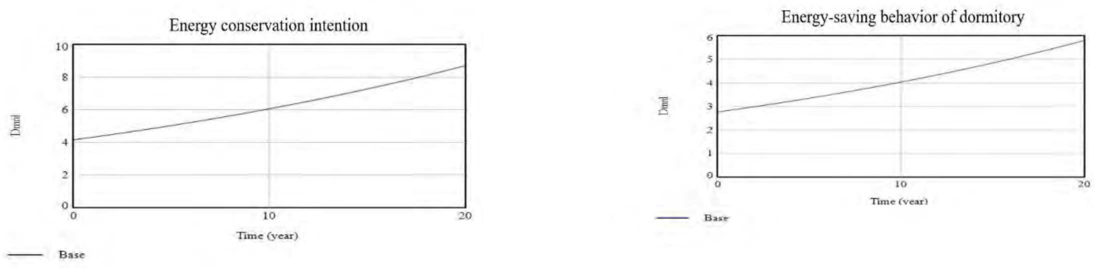


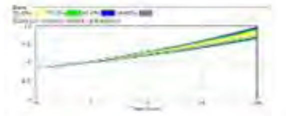
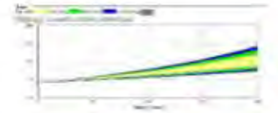
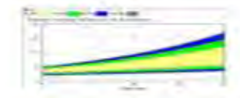
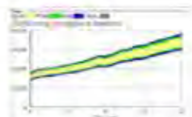
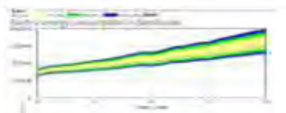
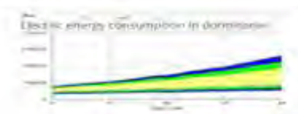
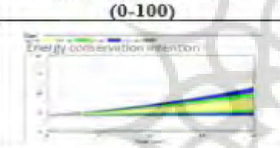
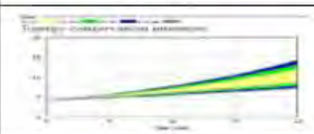
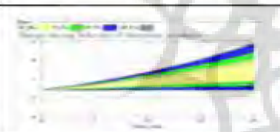
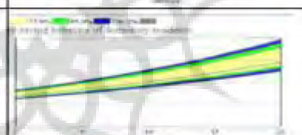
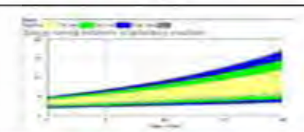
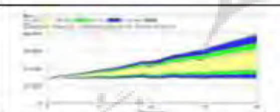
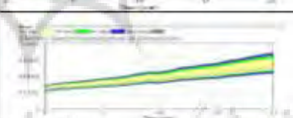
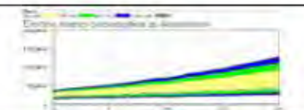
Figure 10. Behavior of the model's target variables over the 20-year simulation horizon

Over the 20-year simulation period (2021–2041), it was observed that both electricity consumption and dormitory debt are projected to continue increasing, consistent with historical trends. Meanwhile, access to advanced equipment is expected to decline. The energy-saving intent and behavior of dormitory residents show a gradual upward trend, though the rate of increase remains modest and does not reflect substantial improvement. Given the observed behavior of the model's target variables during the simulation period—particularly the undesirable trajectory of the electricity consumption curve—and considering the previously articulated dynamic hypothesis and its causal explanations involving reinforcing and balancing feedback loops, the study addresses the following core research questions:

1. What factors contribute to the increased electricity consumption among students?
2. Which behavioral components and variables influence the development of energy-saving behavior among students over time?
3. What policies and interventions effectively promote energy savings among dormitory residents?

A Monte Carlo sensitivity analysis was conducted following the initial simulation to address the first two questions. Based on the results, the variables with the highest influence—i.e., the model's leverage points—were identified. The sensitivity analysis focused on the behavior of three primary target variables: energy-saving intention, energy-saving behavior among residents, and electricity consumption. The model's sensitivity analysis results are presented in Table 4.

Table 4. Monte Carlo Sensitivity Analysis for Model Exogenous Variables and Their Effects on Target Variables

Variable And Range	Impact of climatic and cultural adaptation (0-100)	Allocation of financial resources to energy-saving advertising (0-1)	Allocation of Financial Resources to Energy Management Equipment (0-1)
Energy conservation intention			
Energy-saving behavior of dormitory residents			
Electric energy consumption in dormitories			
Variable And Range	**Perceived image of responsible behavior among dormitory residents (0-100)**	**Allocation of financial resources to education and awareness programs(0-1)**	**Top management support for responsible consumption (0-100)**
Energy conservation intention			
Energy-saving behavior of dormitory residents			
Electric energy consumption in dormitories			

Identification and Evaluation of Policies

A series of electricity consumption optimization policies- grounded in behavioral and psychological factors- were formulated to address the third research question, based on the results obtained from the sensitivity analysis of the system dynamics model and identification of leverage points. These policies align with existing studies and strategic plans and were further validated through expert consultation with energy management and policy-making professionals. The identified policies are categorized into four main strategic groups. Each was implemented in the system dynamics model to evaluate its effect on several key variables: residents' intention to conserve energy in dormitories, their actual energy-saving behaviors, the total electricity consumption of dormitory buildings, outstanding debt levels, the financial resources available for investment in energy-saving measures, and the accessibility of advanced electrical equipment. A detailed description of each strategic group is provided in the subsequent section.

Electricity Consumption Management through Economic Investment in Social Awareness

This strategy focuses on managing electricity consumption by increasing economic investments. It includes policy measures such as investing in advertising, educational outreach, and public awareness initiatives aimed at promoting electricity-saving practices. Additionally, government support mechanisms—such as welfare funds allocated for participation in energy-saving investment opportunities and the reallocation of dedicated revenues to dormitory financial resources—serve to enhance the capital available for energy-saving initiatives. With sufficient financial resources, it becomes feasible to strategically plan and allocate investments toward high-impact areas that support electricity consumption management. Adequate investment and its targeted distribution to educational programs, increased student training, and greater funding for awareness campaigns lead to improved knowledge of energy conservation and heightened awareness of its consequences, benefits, and perceived value. This, in turn, positively influences several behavioral and psychological variables through promoting responsibility, ethical norms, behavioral regulation, and group interaction—ultimately encouraging energy-saving behavior. From another perspective, investment in energy management equipment effectively minimizes energy waste and reduces overall electricity consumption.

Electricity Consumption Management through Dormitory Residents' Energy-Saving Behaviors

This strategy is designed to foster a culture of responsibility in energy conservation among dormitory residents. It aims to instill a sense of commitment and accountability for energy-saving behavior through two distinct policy types. The first category involves cultural policies that focus on cultivating shared values and encouraging a sense of duty among residents. These policies can influence other behavioral factors, given the dynamics and feedback relationships among behavioral variables. The second category encompasses normative policies, establishing formal and prescriptive norms that mandate energy-saving behavior. Within the system dynamics model, these policies are operationalized through changes in variables such as the perceived image of responsible resident behavior and the impact of governmental pressure via increased payment tariffs.

Electricity Consumption Management through Dormitory Administrators' Performance

This strategy is designed with a focus on the behavioral role of dormitory administrators and their influence on residents' energy-related behaviors, ultimately impacting overall electricity consumption. One policy under this strategy involves senior management support for energy-saving behaviors, implemented through incentives and recognition systems that reward residents for adopting conservation practices—thereby fostering motivation and reinforcing sustainable habits. Another policy addresses climate and cultural alignment in room allocation. This entails assigning students to shared rooms based on geographic and climatic proximity, recognizing that individuals from similar regions often exhibit comparable energy-use preferences. By harmonizing these preferences, the strategy aims to reduce diversity in energy consumption habits within shared spaces, thus facilitating more effective energy management at the room level and, by extension, across the entire dormitory. Additionally, the strategy includes targeted monitoring and inspection to identify buildings with unusually high energy consumption. This enables administrators to implement corrective measures and support energy optimization practices—ultimately contributing to reducing waste and preventing excessive electricity usage.

Electricity Consumption Optimization through Increased Investment in Building Modernization

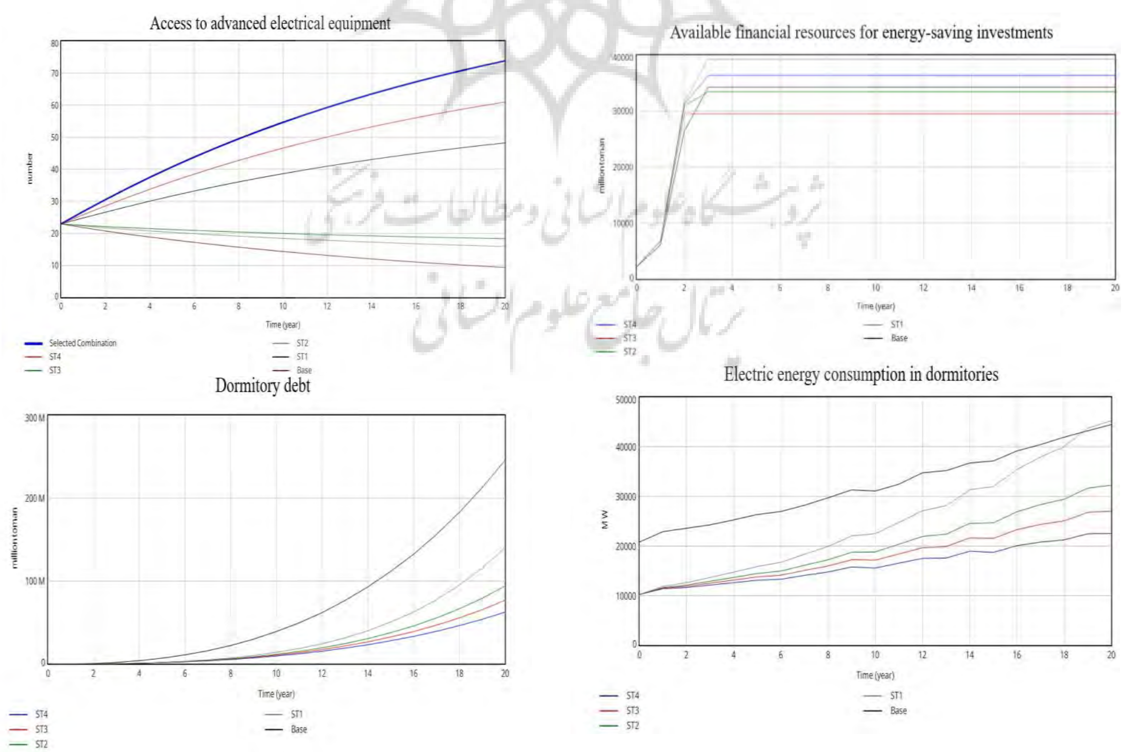
This strategy simultaneously reduces electricity consumption and prevents energy waste by equipping buildings with advanced and efficient technologies. The policy measures are considered from two perspectives. The first focuses on investment in infrastructure upgrades to minimize energy losses, such as installing shading devices for evaporative coolers and enhancing insulation systems. The second perspective targets investment in energy-efficient and innovative technologies, including low-consumption lighting (e.g., LED lamps) and motion sensor systems. These measures are intended to enhance the overall energy performance of dormitory buildings. A summary of the strategic policies, implementation mechanisms, and corresponding changes in model variables is presented in Table 5.

Table 5. Summary of Strategies and Policies for Electricity Consumption System in Tehran University Dormitories Based on Residents' Behavioral Patterns

Strategy	Proposed Policies	Implemented Change in Model Variables
Strategy 1: Electricity Consumption Management through Economic Investment in Social Awareness	Investment in advertising for electricity conservation	Increase in financial resource allocation to energy-saving advertising (from 1.3953 to 1.605195)
	Investment in education and information dissemination for energy conservation	Increase in financial resource allocation to education and awareness programs (from 0.005 to 0.006)
	Government support for investment in energy consumption management	Increase in investment ratio in energy-saving opportunities (from 0.25 to 0.3) Increase in participation in energy-saving opportunities (from 3802 to 4372.3) Increase in the allocation of financial resources to energy management equipment (from 0.25 to 0.2875) Increase in allocation from earmarked revenues to available financial resources for dormitories (from 0.0176 to 0.02024)

Strategy 2: Electricity Consumption Management through Dormitory Residents' Energy-Saving Behaviors	Cultural promotion to foster commitment and responsibility among residents	Increase in perceived image of responsible resident behavior (from 3.92 to 5)
	Establishing legal norms to enforce energy-saving regulations	Increase in the effect of governmental pressure via higher tariffs (from 0.0013 to 0.00195)
Strategy 3: Electricity Consumption Management through Dormitory Administrators' Performance	Support from senior managers for energy-saving behaviors	Increase in senior management support for responsible consumption (from 3.1047 to 5)
	Cultural and climatic matching in resident accommodation	Increase in the effect of climate and cultural compatibility in room allocation (from 1 to 1.5)
	Inspection-based identification of inefficient buildings	Increase in monitoring and inspection for identifying high-consumption buildings (from 0.1 to 0.25)
Strategy 4: Electricity Consumption Optimization through Increased Investment in Building Modernization	Investment in building upgrades to reduce energy loss	Increase in allocation to insulation from financial resources (from 0.1885 to 0.2262) Increase in allocation to shading devices for evaporative coolers (from 0.028 to 0.0336)
	Investment in advanced, low-energy technologies	Increase in allocation to advanced equipment from financial resources (from 0.3632 to 0.41768)

The four proposed strategies were comparatively analyzed after implementing policies on the model's leverage variables and observing resulting changes in the target variables. Figure 11 illustrates the behavior of the model's target variables to facilitate comparison across the four strategies.



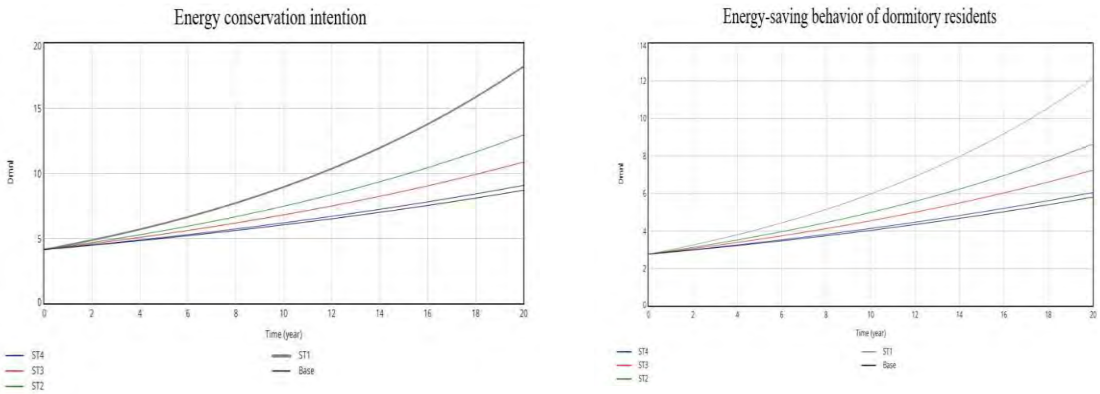


Figure 11. Comparative chart of four strategies based on the policies applied to model variables over the 20-year simulation horizon.

As observed, each strategy focuses on development and improvement from one or two perspectives, and simultaneous enhancement across all key model variables was not achieved. A combined policy strategy was considered because none of the individual strategies resulted in comprehensive improvement of all key variables. Accordingly, after applying each policy separately, as well as in pairs and triplets, various combinations were tested within the model. Key model variables were examined, and the results were compared. The analysis revealed that combining policies from the first and third strategies—as presented in Table 6—offers the most effective solution for improving key variables over the 20-year simulation period. Figure 12 illustrates the outcomes of implementing the selected combined policy strategy on the model's key variables.

Table 6. Selected combined policies from Strategy One and Strategy Three

Strategy	Proposed Policies	Implemented Change in Model Variables
Strategy 1: Electricity Consumption Management through Economic Investment in Social Awareness	Investment in advertising for electricity conservation	Increase in financial resource allocation to energy-saving advertising (from 1.3953 to 1.605195)
	Investment in education and information dissemination for energy conservation	Increase in financial resource allocation to education and awareness programs (from 0.005 to 0.006)
	Government support for investment in energy consumption management	Increase in investment ratio in energy-saving opportunities (from 0.25 to 0.3) Increase in participation in energy-saving opportunities (from 3802 to 4372.3) Increase in the allocation of financial resources to energy management equipment (from 0.25 to 0.2875)

		Increase in allocation from earmarked revenues to available financial resources for dormitories (from 0.0176 to 0.02024)
Strategy 3: Electricity Consumption Management through Dormitory Administrators’ Performance	Support from senior managers for energy-saving behaviors	Increase in senior management support for responsible consumption (from 3.1047 to 5)
	Cultural and climatic matching in resident accommodation	Increase in the effect of climate and cultural compatibility in room allocation (from 1 to 1.5)
	Inspection-based identification of inefficient buildings	Increase in monitoring and inspection for identifying high-consumption buildings (from 0.1 to 0.25)

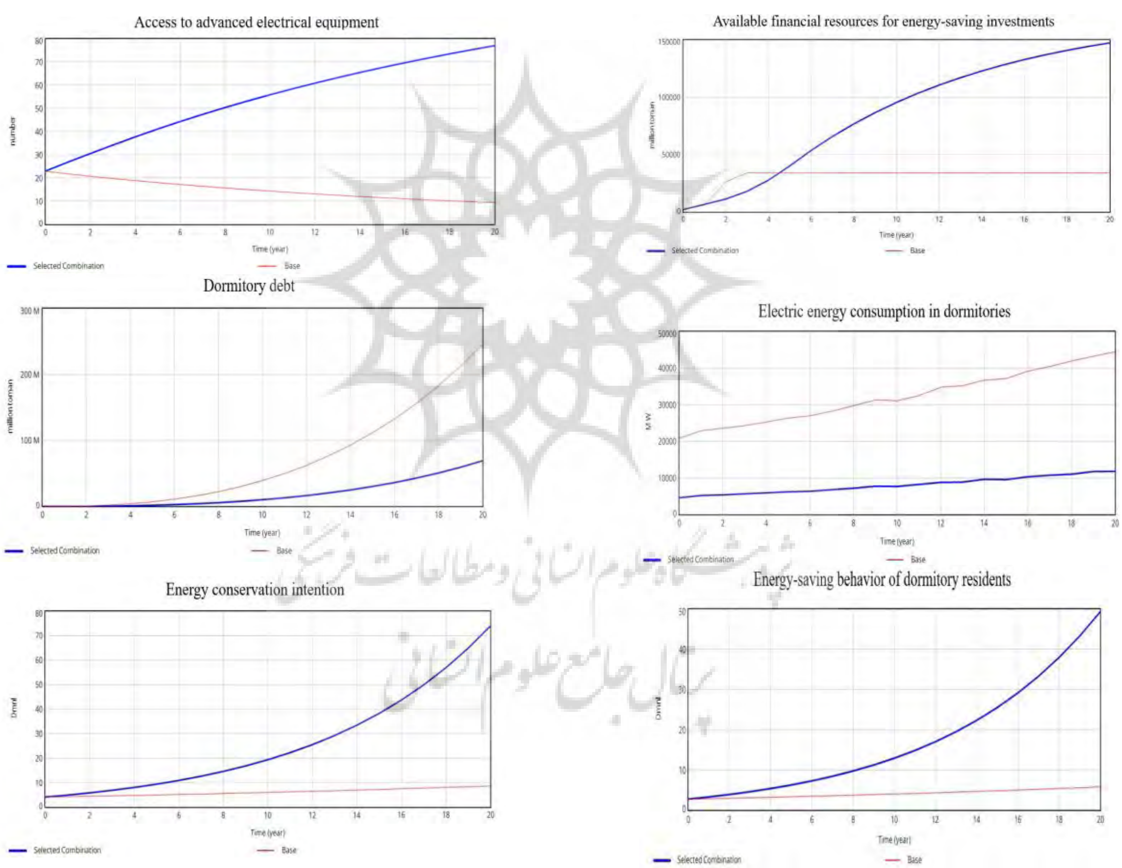


Figure 12. Comparison of the selected combined policy strategy over the 20-year simulation horizon

Discussion and Conclusion

In this study, electricity consumption within a shared space was examined concerning residents’ behavioral patterns, employing a system-based approach to simulate the dynamic behavior of energy consumption over a 20-year horizon (2021–2041). Dormitories at the University of Tehran were selected as the case study. Based on sensitivity analysis results and expert insights from decision-makers, optimal strategies for managing electricity consumption—grounded in residents' behavioral variables—were identified and analyzed.

Policies under Strategy One focused primarily on economic investments in social awareness. Implementation of this strategy increased government and welfare fund participation in energy management investment opportunities, thereby expanding available financial resources for energy-saving initiatives. These investments enhanced education, awareness, and advertising allocations, positively affecting residents' behavioral variables by boosting energy-saving knowledge. This behavioral shift impacted usage patterns across cooling, heating, lighting systems, and personal electrical devices, reducing electricity consumption and significantly lowering dormitory debt.

Strategy Two addressed behavioral dimensions through cultural promotion and normative enforcement. These policies successfully increased energy-saving intention and behavior, reducing electricity consumption and debt. However, no significant changes were observed in other key model variables. It is noteworthy that behavioral improvements seen in Strategy Two—via culture-building and normative mechanisms—also emerged through Strategy One's investments in education and advertising. Consequently, Strategy One effectively covered Strategy Two's objectives, as reflected in the combined policy evaluation where its policies appeared among the selected interventions.

Strategy Three emphasized the performance of dormitory administrators. Support from senior managers for energy-saving behavior fostered motivation and strengthened conservation practices. Climate and cultural compatibility policies—through reduced diversity in residents' energy preferences—effectively managed electricity use at the room and dormitory levels. The strategy also included monitoring and inspection to identify high-consumption buildings. This led to targeted administrative investments in energy optimization (e.g., shading devices for evaporative coolers, improved insulation, and advanced equipment). Collectively, these measures enhanced access to efficient technologies and reduced overall electricity consumption.

The policies of Strategy Four are exclusively focused on equipping buildings to manage energy consumption.

As demonstrated in the results and analysis of strategy implementation, Strategy Three, through the behavioral conduct of administrators, also inherently covers the objectives of Strategy Four. Therefore, the policies in Strategy One, by providing financial resources and investments and influencing behavioral variable, particularly through enhanced social awareness, ultimately reduce electricity consumption and dormitory debt. Meanwhile, Strategy Three addresses the behavioral dimensions of administrators in their interactions with residents, their management approach to dormitory operations, and their investment-related behaviors toward optimizing electricity usage. Additionally, the way administrators perform their duties significantly affects resident behavior.

The synergistic impact of Strategy One (financial and behavioral investments) and Strategy Three (administrative behavioral engagement) creates a comprehensive and inclusive portfolio of policies. This integrated approach effectively enhances all target variables modeled in the system, affirming its robustness in managing energy consumption within shared residential environments.

Following the implementation of the selected combination of policies in the system dynamics model, the following interventions are expected to support electricity consumption management with consideration of residents' behavioral factors:

- **15% increase** in budget allocation for energy-saving advertising and awareness campaigns
- **20% increase** in budget allocation for resident education focused on energy-saving practices
- **15% increase** in government and student welfare fund support through expanded participation and along with a 20% increase in the investment ratio allocated to energy-saving opportunities.
- **Senior management support** for responsible energy consumption was strengthened by 61%.
- **Climate and cultural alignment** among dormitory residents in shared rooms was enhanced by 50%.
- **15% increase** in monitoring and inspection efforts to identify high-consumption buildings

Comparison of Research Findings with Previous Studies

Previous studies have not addressed the comprehensive modeling of electricity consumption management based on behavioral factors. However, in advertising and environmental knowledge, Tang et al. (2019) employed structural equation modeling to examine and confirm the positive effects of advertising, informational campaigns, and descriptive norms on individuals' sense of responsibility and social pressure regarding the intention to conserve energy. Karimi et al. (2021) also confirmed the direct relationship between advertising and environmental knowledge. Using a system dynamics approach, the present study identified the aforementioned variables as leverage points and obtained similar findings. Oktavia et al. (2023), through a fuzzy Analytic Hierarchy Process (AHP), and Zhao et al. (2019) (via regression analysis) emphasized the importance of conservation education and its connection to environmental knowledge and energy-saving behavior—findings that were also reflected in this study. Additionally, (Kim & Seock, 2019; Si-dai et al., 2021), using structural equation modeling, confirmed the influence of environmental awareness and social norms on the intention and behavior of purchasing energy-efficient equipment, which aligns to some extent with the present research results.

Hong et al.,(2019)Using statistical methods, it was demonstrated that government subsidy policies play a critical role in promoting energy-saving behaviors and exert a significant moderating effect on attitudes and behaviors related to energy conservation. Accordingly, this aligns with parts of the present study's findings concerning government support. Moreover, Weerasinghe et al. (2023) Employing machine learning techniques, the study identified senior management support and the availability of resident control settings as key predictors of energy-saving behaviors—findings that correspond to this research's aspects. The present study proposes a conceptual framework by drawing on existing behavioral theories and evaluating their effectiveness in influencing dormitory residents' energy-saving actions. The author argues that focusing on behavioral and psychological factors, alongside other determinants, can facilitate energy-saving behaviors and ultimately contribute to reduced energy consumption.

Practical Recommendations and Future Research Directions

This section outlines key practical insights derived from the study, alongside recommendations for future research aimed at extending and validating the findings.

Practical Recommendations

1- Enhancing Incentive Policies and Sustainable Investment
- Develop support programs for energy-saving behavior by allocating financial resources to incentives and offering managerial support to residents with efficient consumption patterns.
- Expand the adoption of innovative technologies, including energy monitoring systems, intelligent lighting controls, and optimization of heating and cooling systems.

2- Strengthening Education and Awareness
- Conduct continuous training programs to increase residents' knowledge of energy-saving methods and their cost-reduction impact.
- Launch widespread media campaigns to promote individual and collective responsibility regarding energy consumption.

3- Improving Managerial and Regulatory Policies
- Increase the role of senior managers in energy governance by establishing efficient policies for consumption oversight and encouraging conservation behavior.
- Enhance supervision and assessment of high-consumption buildings through corrective actions such as improved insulation, advanced ventilation systems, and modern energy management tools.

4- Adapting Climate and Cultural Structures in Student Dormitories
- Align room allocation with climatic and cultural conditions to reduce diverse thermal demands and related energy consumption in shared spaces.

Future Research Directions:

1- Expand to Diverse Urban Contexts: Investigate other cities with varying cultural and climatic conditions to enhance generalizability.
2- Evaluate Policy Impacts: Assess how governmental subsidies and incentives shape energy-saving behaviors.
3- Use Longitudinal Methods: Track behavioral changes over time for more robust insights.
4- Explore Renewable Energy in Dormitories: Examine the feasibility and impact of integrating sustainable energy sources in academic housing.

Data Availability Statement

Data available on request from the authors

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

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