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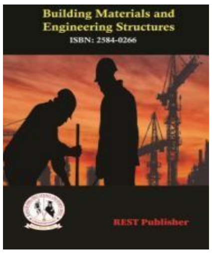

State Of the Art of Advanced Solar Control Devices for Buildings Using WSM Method

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Abstract: *The growing urgency of climate change and depletion of traditional energy resources possess spurred a global shift towards renewable energy solutions. Among these, solar energy has emerged as a leading contender, offering a sustainable and inexhaustible source of power. Solar buildings, which integrate solar energy systems into their design and functionality, represent a significant innovation in the quest for energy efficiency and environmental sustainability. Solar buildings harness solar power through technologies such as photovoltaic (PV) panels, solar thermal systems, and passive solar design principles. These buildings are designed to maximize energy capture, reduce dependence on fossil fuels, and minimize carbon footprints. By incorporating solar energy solutions, they not only contribute to the mitigation of climate change but also promote energy independence and reduce utility costs for occupants. Solar Buildings play a crucial role in tackling the urgent challenge of climate change. By harnessing solar energy, these buildings significantly reduce greenhouse gas emissions, contributing to a lower carbon footprint. Research in this area advances our understanding of how solar technologies can be optimized to maximize energy efficiency and minimize environmental impact. This knowledge is vital for developing strategies to meet international climate goals and transitioning to a low-carbon. Alternative: Solar Building a Solar Building B Solar Building C Solar Building D Solar Building E Evaluation Preference: Energy Efficiency (kWh/m²)), Solar Power Generation (kW)), Initial Installation Cost ($), Maintenance Cost ($/year). The results indicate that solar building c Attained the top position, while solar building b had the lowest position achieved. "The dataset's significance regarding solar building, according to the wsm Method, Company D achieves the highest ranking."*

Key words: *Solar energy, PV panels, and solar thermal systems, Passive solar design, Energy efficiency.*

1. INTRODUCTION

Solar energy has the potential to utilized to generate generating electricity through photovoltaic panels. to produce heat using solar thermal collectors. These technologies are applied in various ways to support heating and cooling systems through different conversion processes Collectors are indeed commonly "Accustomed to furnishing hot water. in buildings. Particularly in numerous European nations. In Austria and Germany, solar combi-systems are crucial for fulfilling heating requirements, often installed in private homes, featuring substantial buffer tanks, typically ranging from 800 to 2000 liters, along with a solar thermal collector array spanning 10 to 20 square meters. systems "Can be adapted for cooling through integration with a thermally powered cooling device. "Passive solar design configurations are classified into five types Sure, here are some paraphrased definitions for those terms: Direct solar gain: Utilizing sunlight entering directly into a building to provide warmth and lighting. Isolated solar gain: Harnessing solar energy in a controlled way to optimize heating or cooling within a building. Thermal storage mass: Materials used in construction that absorb and store heat energy from sunlight "During daytime for gradual nighttime release, regulating indoor temperatures. Passive cooling: Design strategies that naturally cool indoor spaces without mechanical systems, often using shading, ventilation, and thermal mass. Active solar energy: Technologies that convert sunlight into electricity or heat, such as solar panels or solar water heaters, to actively power or supplement building energy needs. which is aimed at capturing usable heat from solar radiation. In temperate climates, for instance, solar radiation is effectively used to supplement traditional heating systems or to generate electricity. Solar radiation is regarded as a primary source of renewable energy While solar energy can be used directly, it also affects the Earth's climate. Opportunities for harnessing energy arise from waves, tides, and wind, all driven by solar energy. Solar technologies are primarily Converting solar radiation into other forms of useful energy optimizing the use of solar energy in buildings. Solar collectors can enhance building envelopes, such as transforming a flat roof into an angled "solar roof" or expanding space with a "solar attic." A wall incorporating transparent insulation can decrease losses in transmission and harness solar energy gains, providing passive low-temperature wall heating, which is particularly important in renovation projects. This paper examines the dual outputs of electricity and thermal energy provided by energy-efficient systems. It compares the solar energy capacity of residential buildings in different urban settings, particularly focusing on building orientation, azimuth, and site coverage. Transparent insulation (TI) can be applied to thick walls to enhance energy efficiency. Uninsulated sun-facing walls can be improved with wall insulation, offering a comprehensive solution to degradation issues, enhancing comfort, and improving building aesthetics. Solar photovoltaic (PV) and solar collector technologies can be incorporated into building structures "To create building-integrated photovoltaic/thermal (PV/T) systems, which supply both electricity and hot water". Recent years have seen significant improvements in efficiency and cost reductions for solar PV, making solar electricity increasingly economically viable. Hybrid PV-thermal (PVT) collectors were found by Yan et al. [2] to offer electricity costs lower than grid-supplied prices in all 344 Chinese cities studied, even without subsidies. gaining attention for their high. Computer simulations are utilized to analyze how these variables affect solar potential across low, medium, and high site densities. Different types of shading strategies, including "External and intermediate devices, including both fixed and portable options," are compared for their effectiveness in this analysis. and related citations are omitted, while specific Internal Solar Shading: Research on the effectiveness of blinds, shades, or curtains in reducing solar heat gain and improving energy efficiency in buildings. Studies on the impact of different shading materials (like textiles, plastics, or composites) on indoor thermal comfort and energy consumption. Solar Film Coatings: Technical evaluations of various types of solar control window films, their optical properties, and their performance in terms of heat rejection, glare reduction, and UV protection. Case studies or experimental research on the application of solar films in different climates and building types. For references, you can explore academic databases like Google Scholar, IEEE Xplore, or research journals in architecture, building science, or materials science. These sources typically provide detailed insights and empirical data on the effectiveness and applications of internal solar shading and solar film coatings. are included due to their relevance in evaluating external and intermediate shading solutions. The following sections highlight key studies addressing these subjects. Additionally, solar chimneys are recognized for promoting natural ventilation, which enhances indoor thermal comfort by bringing fresh air into houses. The, featuring a glass cover, is a widely recognized application in this regard. The LRE building represents a pinnacle of solar element integration, illustrating how these components can be seamlessly integrated into original designs. However, complete integration isn't always essential; often, aesthetic harmony is prioritized over invisibility Given the defined To assess the effectiveness of the proposed controller and the successful operation of the weather prediction modules, especially in comparison to previous studies This study investigates how solar electric compression refrigeration differs from solar thermal methods like mechanical compression, absorption, adsorption, and solid desiccant cooling systems are employed. The system's performance is greatly impacted by the installation method and the type of solar collectors used, as these determine the amount of solar irradiation collected.

2. MATERIALS AND METHOD

The test setups for three types of solar systems are depicted The PV system includes a 0.438 m² PV module and a 12 V battery connected to a 12 V PV controller. Sunlight is converted into electricity generated by PV cells, which are controlled by the system. The PV/T solar system comprises a solar collector system featuring an efficient collection area in square meters, along with essential components such as a a 12-volt circulation pump battery, and a 12-volt PV module controller. to enhance energy capture and utilization r, and a 100-liter water storage tank. Sunlight penetrates through a glass cover, interacting with the PV layer. PV cells convert a portion of the sunlight into electricity, which is stored in a battery. The excess energy is transformed into heat, which is absorbed by the water circulating within the system. PV/T This approach seeks to gather data on existing energy consumption patterns in the building sector, focusing initially on evaluating the use of renewable energy. It involves conducting field surveys and a thorough review, utilizing both qualitative and quantitative data collection methods. The initial phase of the research examines the effectiveness of passive solar methods and active solar technologies in tall building design, utilizing the comparative study aims to assess building performance across varying shading conditions using commercially available modules and standardized frameworks. This study focuses on evaluating external and intermediate shading devices, encompassing both fixed and movable options. For consistency in comparison, certain strategies and their references were excluded: internal shading systems, which depend significantly on user behavior; self-shading structures; and solar film coatings on windows, which diverge significantly from conventional shading devices. Nevertheless, the study does include a few references pertaining to internal shading systems and solar film coatings. Additionally, it incorporates references that specifically analyze external or intermediate shading systems. Another module, not depicted in Figure 2, manages input/output functions and internally buffers parameters. Inputs include data from the previous time interval, stored values from the six preceding intervals in the buffer. The output determines the next time step's control action step. It's important to note that numerical tests conducted during the module development demonstrated that a one-step-ahead forecast is adequate. On-site experimental testing of various versions of the controller confirmed its satisfactory performance to evaluate the effectiveness status for buildings; three iterations of a building model were simulated. Building A integrates a hybrid system Building B features a PV/T system along with PV modules, reflecting the original design, whereas Building C only utilizes PV modules. Notably, all iterations employ an identical hydroid heating system.

Step 4. Design of decision matrix and weight matrix

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \qquad (1)$$

The weight vector may be expressed as,

$$w_j = [w_1 \quad \cdots \quad w_n] \qquad (2)$$

$$where \sum_{j=1}^{n} (w_1 \quad \cdots \quad w_n) = 1$$

Step 5. Normalization of DM

$$n_{ij} = \begin{cases} \dfrac{x_{ij}}{max.x_{ij}} & \mid j \in B \\ \dfrac{min.x_{ij}}{x_{ij}} & \mid j \in C \end{cases} \qquad (3)$$

Where n_{ij} is the normalized value of the i^{th} alternative for the j^{th} criterion, $max.\, x_{ij}$ and $min.\, x_{ij}$ are maximum and minimum value of x_{ij} in the j^{th} column for the benefit (B) and cost criteria (C) respectively.

Step 6. Weighted normalized Decision Matrix

$$W_{n_{ij}} = w_j n_{ij} \qquad (4)$$

Step 7. Ranking of alternatives

$$S_i^{WSM} = \sum_{j=1}^{n} w_j n_{ij} \qquad (5)$$

Where, S_i^{WSM} is the ranking score of the i^{th} alternative, w_j is weight of the j^{th} criterion. Then the alternatives are ranked in descending order with highest S_i^{WSM} being ranked highest

Strengths

Weighted sum model (WSM) facilitates clear structuring of the problem at hand by explicitly outlining alternatives, criteria, and their respective scores and weights. This approach is straightforward, user-friendly, and highly effective for addressing multi-criteria problems. It provides a transparent depiction of prioritized criteria and simplifies the entire computation process for better comprehension.

Weakness

One significant limitation observed in most Multiple Criteria Decision Making (MCDM) techniques is the subjective nature of assigning weights. This process demands deep understanding and precision, as the accuracy of weights can vary depending on the specific problem and circumstances. Furthermore, accurate weight summation assumes additivity among attributes, which may not always be realistic, posing a challenge in certain scenarios.

3. RESULT AND DISCUSSION

TABLE 1. Solar Building

	DATA SET			
	Energy Efficiency (kWh/m^2)	Solar Power Generation (kW)	Initial Installation Cost ($)	Maintenance Cost ($/year)
Solar Building A	180	50	30000	1500
Solar Building B	160	45	28000	1400
Solar Building C	200	55	32000	1600
Solar Building D	170	48	29000	1450
Solar Building E	190	53	31000	1550

The dataset details the energy efficiency, solar power generation, initial installation cost, and maintenance cost for five solar buildings. Solar Building A has an energy efficiency of 180 kWh/m^2, generates 50 kW of solar power, and incurs an initial installation cost of $30,000 with an annual maintenance cost of $1,500. Solar Building B, with an energy efficiency of 160 kWh/m^2, produces 45 kW of solar power, and has a lower initial installation cost of $28,000 and a maintenance cost of $1,400 per year. Solar Building C stands out with the highest energy efficiency of 200 kWh/m^2 and solar power generation of 55 kW, costing $32,000 for installation and $1,600 annually for maintenance. Solar Building D has an energy efficiency of 170 kWh/m^2, generates 48 kW of solar power, and has an installation cost of $29,000 with a yearly maintenance cost of $1,450. Lastly, Solar Building E offers an energy efficiency of 190 kWh/m^2, generates 53 kW of solar power, and has an installation cost of $31,000 with an annual maintenance cost of $1,550. These buildings vary in terms of their energy efficiency and costs, providing a range of options for consideration in solar energy implementation.

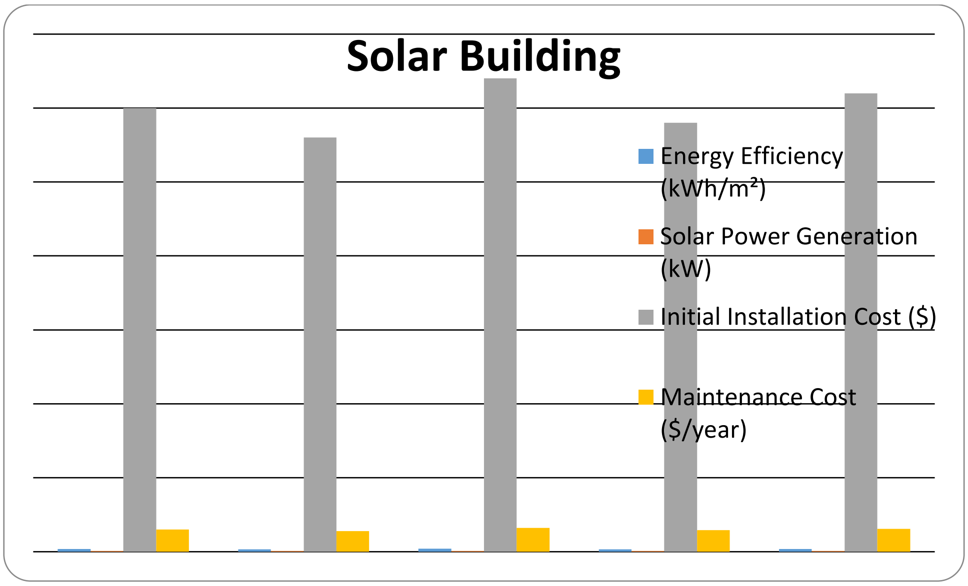

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FIGURE 1. Solar Building

Figure 1 illustrates the data set, detailing energy efficiency, solar power generation, initial installation cost, and maintenance cost for five solar buildings. Solar Building A has an energy efficiency of 180 kWh/m^2, generates 50 kW of solar power, and has an initial installation cost of $30,000 with an annual maintenance cost of $1,500. Solar Building B, with an energy efficiency of 160 kWh/m^2, produces 45 kW of solar power, and has a lower initial installation cost of $28,000 and a maintenance cost of $1,400 per year. Solar Building C stands out with the highest energy efficiency of 200 kWh/m^2 and solar power generation of 55 kW, costing $32,000 for installation and $1,600 annually for maintenance. Solar Building D has an energy efficiency of 170 kWh/m^2, 48 kW of solar power generation, an installation cost of $29,000, and a yearly maintenance cost of $1,450. Lastly, Solar Building E offers an energy efficiency of 190 kWh/m^2, produces 53 kW of solar power, and has an installation cost of $31,000 with an annual maintenance cost of $1,550. These buildings differ in terms of their energy efficiency and costs, providing a range of options for consideration in solar energy implementation.

TABLE 2. Normalized

Normalized			
0.00000	0.90909	0.93333	0.93333
0.80000	0.81818	1.00000	1.00000
1.00000	1.00000	0.87500	0.87500
0.85000	0.87273	0.96552	0.96552
0.95000	0.96364	0.90323	0.90323

The normalized data set shows values for energy efficiency, solar power generation, initial installation cost, and maintenance cost for five solar buildings, scaled between 0 and 1. The first building scores 0.00000 for energy efficiency, 0.90909 for solar power generation, and 0.93333 for both initial installation and maintenance costs. The second building scores 0.80000 for energy efficiency, 0.81818 for solar power, and a perfect score of 1.00000 for both costs. The third building achieves the highest score of 1.00000 for energy efficiency and solar power generation, but scores 0.87500 for both costs. The fourth building scores 0.85000 for energy efficiency, 0.87273 for solar power, and 0.96552 for both costs. The fifth building scores 0.95000 for energy efficiency, 0.96364 for solar power, and 0.90323 for both costs. This normalization enables a straightforward comparison of each building’s performance and cost efficiency across different metrics.

TABLE 3. Weight

Weight			
0.25	**0.25**	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25

Table 3 shows a weight matrix where each criterion—energy efficiency, solar power generation, initial installation cost, and maintenance cost—is equally assigned a weight of 0.25 across all five solar buildings. This ensures that each criterion contributes equally to the overall evaluation of the buildings' performance and cost-effectiveness. By assigning equal weights, the analysis aims to deliver a balanced assessment, preventing any single factor from dominating the evaluation process. This approach facilitates a fair comparison among the buildings, highlighting the importance of considering all criteria equally in decision-making processes related to solar energy implementation and building sustainability.

TABLE 4. Weighted normalized decision matrix

Weighted normalized decision matrix			
0.22500	0.22727	0.23333	0.23333
0.20000	0.20455	0.25000	0.25000
0.25000	0.25000	0.21875	0.21875
0.21250	0.21818	0.24138	0.24138
0.23750	0.24091	0.22581	0.22581

The weighted normalized decision matrix provided represents the composite evaluation scores for five solar buildings across four key criteria: energy efficiency, solar power generation, initial installation cost, and maintenance cost. Each score reflects how well each building performs relative to the others when considering the specified weights for each criterion. For instance, the first building achieves scores of 0.22500 for energy efficiency, 0.22727 for solar power generation, and 0.23333 for both installation and maintenance costs. The second building scores 0.20000 for energy efficiency, 0.20455 for solar power, and 0.25000 for both costs. The third building scores 0.25000 for energy efficiency and solar power, and 0.21875 for both costs. The fourth building scores 0.21250 for energy efficiency, 0.21818 for solar power, and 0.24138 for both costs. The fifth building scores 0.23750 for energy efficiency, 0.24091 for solar power, and 0.22581 for both costs. These scores are calculated by multiplying the normalized values from the previous table with the corresponding weights and summing them up for each building. This process ensures that the evaluation reflects the relative importance of each criterion as defined by the weights assigned, providing a more nuanced and weighted comparison of the buildings' overall performance and cost efficiency in solar energy utilization.

TABLE 5. Preference Score

	Preference Score
Solar Building A	0.91894
Solar Building B	0.90455
Solar Building C	0.93750
Solar Building D	0.91344
Solar Building E	0.93002

The preference scores listed represent the overall evaluation of five solar buildings based on their performance across multiple criteria. Solar Building C achieved the highest preference score of 0.93750, indicating it performed the best overall according to the criteria and their assigned weights. Following closely behind are Solar Building E with a score of 0.93002 and Solar Building A with 0.91894, showing strong performance in the evaluation. Solar Building D and Solar Building B scored 0.91344 and 0.90455, respectively, indicating slightly lower but still competitive performance relative to the others. These scores are derived from a comprehensive assessment that likely considers factors like energy efficiency, solar power generation, initial installation costs, and maintenance costs, providing a clear ranking to facilitate decision-making in selecting the most suitable solar building based on specific project requirements or preferences.

TABLE 6. Preference Score

	Rank
Solar Building A	3
Solar Building B	5
Solar Building C	1
Solar Building D	4
Solar Building E	2

The rankings of the five solar buildings reflect their relative performance across aggregated evaluation criteria. Solar Building C leads with rank 1, indicating it excels in areas such as energy efficiency, solar power generation, installation costs, and maintenance costs. Solar Building E follows closely in 2nd place, also showing strong performance across these metrics. Solar Building A holds the 3rd rank, performing well but slightly less than the top two. Solar Building D ranks 4th, performing adequately but less competitively than the top three. Solar Building B ranks 5th, indicating the lowest overall performance based on the evaluated criteria. These rankings help stakeholders make informed decisions about which solar building best aligns with their specific needs and preferences, considering both performance and cost-efficiency factors.

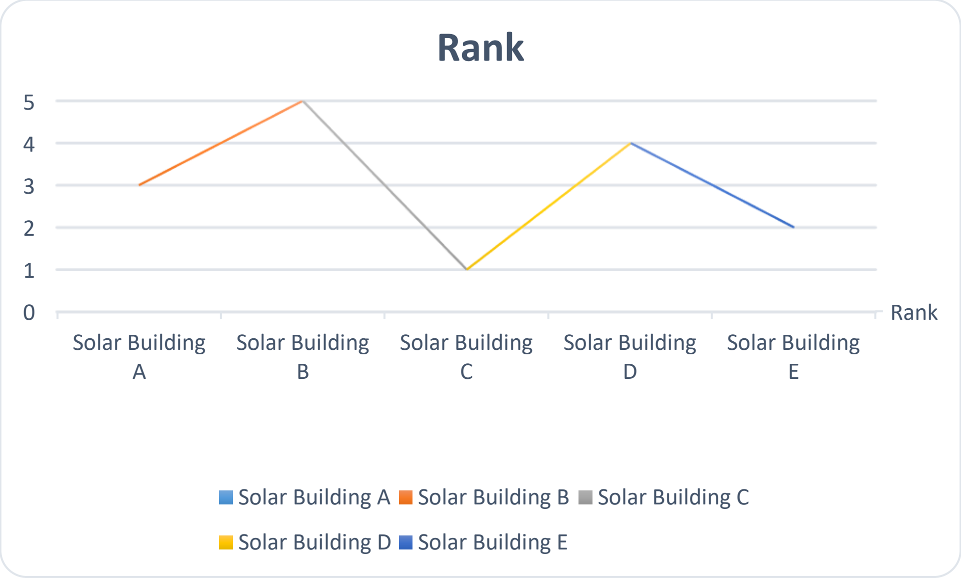

FIGURE 2. Rank

Figure 2 presents the rankings of the five solar buildings based on aggregated evaluation criteria. Solar Building C is ranked 1st, signifying its top performance across metrics such as energy efficiency, solar power generation, installation costs, and maintenance costs. Solar Building E follows closely in 2nd place, indicating strong performance in these areas. Solar Building A holds the 3rd position, performing well but not as highly as the top two. Solar Building D is ranked 4th, showing adequate performance but less competitiveness compared to the top three. Lastly, Solar Building B is in 5th place, indicating the lowest overall performance based on the evaluated criteria. These rankings assist stakeholders in making informed decisions regarding the solar building that best meets their needs and preferences, taking both performance and cost-efficiency into accoun.

4. CONCLUSION

In practical applications, solar chimneys can be incorporated Paraphrasing refers to rephrasing a text while retaining its original meaning. In the context of "into either walls or roofs," we could rephrase this as: Converted into walls or roofs Transformed into walls or roofs Used to create walls or roofs Adapted for walls or roofs Incorporated into walls or roofs, resulting in two primary Arrangements: wall -integrated and roof-integrated. mounted solar collectors (such as solar walls or Trom be walls) and roof-mounted solar collectors. They serve multiple purposes: improving indoor thermal conditions through natural ventilation in buildings without air conditioning, and reducing accumulated heat in buildings equipped Solar chimneys, when used with air conditioning systems, are attracting interest for their ability to reduce Facilitating natural cooling or heating in commercial and residential buildings offers significant benefits by reducing heat gain, operational costs, energy consumption, and carbon dioxide emissions. emissions. They are particularly suitable for regions with ample solar radiation The impact of Mutual shading has a greater impact on PV (photovoltaic) yield rather than on ST (solar thermal) yield. In high-density scenarios, factors like a building aspect ratio of 4 and an azimuth of 0 can lead to mutual shading, which can decrease PV yield. by as much as 47.5%., which is more than twice the decrease observed in ST yield, which is 19.5%. Although increasing the Although increasing the building aspect ratio can enhance solar potential, it also exacerbates mutual shading effects. Furthermore, aspect ratio influences photovoltaic (PV) yield more significantly than solar thermal (ST) yield.". A simplified model and computer program were developed to quantify the flow rate of solar-assisted natural ventilation, considering variations in climatic conditions and heat storage in chimney walls over time. The model's results accurately predicted experimental outcomes obtained using tracer gas measurement techniques. Solar desiccant cooling systems have high cooling capacity and consume substantial energy for supply and exhaust air fans. They effectively provide excess fresh air to functional spaces, ensuring Improving indoor air quality and the effectiveness of ventilation underscores the potential application of solar energy solid desiccant cooling remains viable. Previous studies have recommended double or triple glazing for winter heating, but they suggest that such measures may not be cost-effective for solo summer cooling. The ability of solar absorber materials to absorb and emit radiation plays a crucial role in enhancing their performance.", with absorptivity being particularly crucial. Insulating walls can improve the efficiency of solar chimneys, where a 5 cm thickness of insulation is generally considered sufficient; thicker insulation above 10 cm shows no significant additional improvement. Solar chimneys are often questioned in areas with insufficient solar radiation; however, studies have shown their feasibility with increased absorber area. Dense development is encouraged and may lead to future densification of surrounding areas, but it may not be ideal for net energy use without efficient public transit. In areas lacking public transit, dense development combines low solar availability with high transportation energy. Conversely, low-density development in the city core can minimize energy use at the household level. However, using high-value land for low-density developments pushes the city outward, increasing transportation energy use for remaining households. Instead, cities should aim to concentrate the maximum number of people where transportation energy is minimized. Ontario's Places to Grow plan promotes this type of densification (Ontario Ministry of the Environment, , it was generally observed that cloudier climates disproportionately reduce the performance of low-density development, thereby favoring higher density. Conversely, sunnier climates tend to favor lower density. Assuming everything else remains constant, except for less extreme temperatures (cooler summers and milder winters), compact building forms would be less advantageous because heating and cooling energy demands become more significant. Simulation results indicated that in urban residential buildings in demonstrated that solar thermal (ST) systems delivered the greatest "Heat gain refers to the increase in thermal energy that is beneficial, while PV/T systems produced the highest quantity of equivalent useful thermal energy in these areas. Additionally, the ST system required minimal additional for domestic hot water heating, assuming a thermal energy recovery factor of 1, the PV/T system was evaluated across four regions Among the seven solar systems (S1-S7), analyzed, the combined solar thermal (ST) and photovoltaic (PV) system (S3) demonstrated the highest heat gain and useful thermal energy. for rural homes in Hong. However, it generated the least PV electricity and had the highest amount of unused thermal energy. In comparison, the PV-only system (S1) produced the highest amount of PV electricity but yielded the lowest overall useful equivalent thermal energy.

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