Proceedings of CONF-MCEE 2026 Symposium: Advances in Sustainable Aviation and Aerospace Vehicle Automation
DOI: 10.54254/2755-2721/2026.KA28340

The Impact of Residential Spatial Planning on Residential Travel Carbon Emissions under the Carbon Reduction Model

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Abstract. With the acceleration of global urbanization, urban residential areas have become a significant source of carbon emissions from resident travel. Focusing on the impact of residential spatial planning on travel carbon emissions, this study integrated the "5D" built environment, residents' socioeconomic attributes, and subjective perception factors through case studies and systematic reviews, and explored their comprehensive influence mechanism on residents' travel carbon emissions. The study showed that open neighborhoods with high road density, a high mix of land uses, and high public transit accessibility can shorten travel distances, increase the proportion of walking and public transportation, and thus effectively reduce resident travel carbon emissions. In addition, the analysis emphasized that compact, well-connected communities not only lower carbon intensity but also improve livability and social equity. This paper further proposed strategies such as optimizing spatial form, improving supporting facilities, building a green transportation system, and introducing smart technologies and policy guidance, thereby providing theoretical references and practical guidance for future low-carbon residential planning and sustainable urban development.

Keywords: Carbon Reduction, Transportation, Residential Model.

1. Introduction

As global urbanization continues to advance, it has significantly enhanced societal efficiency and the centralization and quality of public services. However, the dense concentration of population and economic activities has also led to a continuous rise in urban energy consumption. According to authoritative data from the United Nations Environment Programme (UNEP), global cities emit approximately 2.6 billion tons of carbon annually, accounting for over 70% of total global carbon emissions. Among these, carbon emissions from residents' transportation account for about 15%, making it one of the fastest-growing sources of carbon emissions

For a long time, China's economic and social development has been highly dependent on traditional fossil energy such as coal and oil, and urban expansion has further exacerbated the soaring trend of carbon emissions. Data shows that China's urbanization rate has increased from 17.9% in 1978 to 65.2% in 2022, but the location development shows significant unbalanced characteristics - there are both medium and high-density urban areas with unprecedented density and suburbs with extremely loose layout. With the intensification of urban scale and the separation of

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employment and housing, residents' rigid demand for motorized travel continues to rise, directly driving the steady growth of private car ownership. As of the end of 2024, the national civil car ownership has reached 352.68 million. This series of changes undoubtedly poses new and severe challenges to carbon emission control work.

There are various ways to influence residents' travel patterns and control the growth of carbon emissions: including positive guidance such as expanding public transportation coverage and providing economic incentives for low-carbon travel, as well as restricting high-carbon travel such as number restrictions and purchase restrictions. What can really affect the demand and mode of travel from the root is scientific urban spatial planning. This approach is also central to achieving the "Sustainable Cities and Communities" goal of the United Nations Sustainable Development Goals (SDGs).

A commercially mixed-use, walkable neighbourhood with efficient public transport minimises the need to travel by car (the private variety), while sprawling mono-functional housing estates trap their dwellers into high-carbon mobility patterns. Therefore, the connection between spatial design and travel emissions is of fundamental importance to those cities that intend to reconcile economic growth and environmental sustainability.

Through configuring the physical environment within which people decide how to get around in their everyday lives, planners do indirectly but continuously weigh on residents' decisions about sources of travel. A commercially mixed-use, walkable neighbourhood with efficient public transport minimises the need to travel by car (the private variety), while sprawling mono-functional housing estates trap their dwellers into high-carbon mobility patterns. Therefore, the connection between spatial design and travel emissions is of fundamental importance to those cities that intend to reconcile economic growth and environmental sustainability. Based on the theory of new urbanism, Rahnama et al. [1] proposed that TND (traditional neighborhood development) and TOD (transit-oriented development) models can achieve functional integration and humanized design in spatial organization, which can promote walking and public transportation use. Lei et al. [2] found through empirical analysis that road network density and land mix are significantly negatively correlated with residents' travel carbon emissions, indicating that the spatial pattern of "small blocks, dense road network, and functional integration" helps to reduce dependence on private cars. Rong et al. [3] started with the differences in residential types and quantitatively compared the carbon emission levels of open and closed communities, pointing out that open blocks have obvious advantages in promoting low-carbon travel.

In international research, De Vos et al. [4] emphasized the moderating effect of residents' socioeconomic attributes and subjective attitudes on travel choices; Chen et al. [5] proposed that residents' lifestyle preferences and perceptions of the travel environment may explain travel mode differences better than the objective spatial environment. Ibraeva et al. [6] proposed the "5D" theory (Density, Diversity, Design, Destination Accessibility, Distance to Transit) to systematically summarize the impact of the built environment on travel; Ewing and Cervero [7]'s subsequent research further verified the stable influence of these factors on travel mode choice and carbon emission intensity. Sharifi et al. [8] emphasized that the synergistic effect of land use policy and traffic demand management is an important institutional guarantee for reducing carbon emissions. Domestic scholars Wang et al. [9] and Zhan et al. [10] also expanded the empirical research on the relationship between residential patterns and travel carbon emissions from the aspects of land mix, public transportation accessibility, and street design.

Nevertheless, current literature still faces several limitations. First, existing studies mostly focus on single-dimensional spatial or social factors, and lack a systematic explanation of the interaction

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mechanism of “physical space—socioeconomic attributes—subjective perception.” Second, many analyses are based on static or cross-sectional data, which cannot capture the dynamic evolution of residents’ travel behaviors over time or in response to new urban policies. Third, there is insufficient attention to micro-residential scale studies, where spatial configurations directly affect daily mobility choices. Finally, while international research provides useful frameworks such as the 5D model, the applicability of these frameworks to rapidly urbanizing Chinese cities with different cultural norms and institutional contexts remains underexplored.

Therefore, this paper integrates the “5D” built environment, residents’ socioeconomic attributes, and subjective perception factors through case studies and systematic reviews to explore their comprehensive mechanism of influence on residents’ travel carbon emissions. By combining insights from both domestic and international scholarship, the study seeks to fill theoretical gaps, provide empirical evidence at the residential level, and contribute to planning practices aimed at achieving low-carbon urban development. The results are expected not only to enrich the academic understanding of spatial planning and mobility but also to offer practical guidance for policymakers striving to meet China’s “dual carbon” goals and the global agenda of sustainable urban transition.

2. Analysis of differences in residents travel carbon emissions under typical residential patterns

As the basic unit of residents' daily life, residential areas not only bear the function of living, but also serve as the starting point and end point for activities such as commuting, shopping and leisure. In the process of urbanization, China has formed two main types of typical living patterns. One is the closed large community. It is characterized by high internal independence, relatively safer, and provides a more peaceful living environment, but in terms of spatial pattern, it presents a large block and a relatively single function, which increases the travel distance of residents. The other category is open blocks. It is mainly composed of small blocks, with a dense road network and rich functions, and the demand for transportation accessibility and sharing of public spaces is driven by higher demand. Closed communities are more dependent on motor vehicles due to the long travel distance, resulting in higher carbon emissions, while open blocks can meet the needs of more types of residents within the unit range and promote green travel. Therefore, it is of great significance to conduct an in-depth analysis of the travel differences in different residential modes and reveal their action paths and internal mechanisms for promoting urban low-carbon development and optimizing spatial planning.

The residential patterns also have a direct impact on residents' travel patterns through physical spatial characteristics. The "5D" model proposed by Ewing and Cervero [7], namely Density, Diversity, Design, Destination Accessibility, and Distance to Transit, provides a theoretical framework for analyzing this relationship. In terms of density, higher development intensity and population density can shorten travel distances and encourage residents to use public transportation more, thereby reducing carbon emissions, but if the density is too high, it may bring hidden concerns about traffic congestion and reduced living comfort. In terms of diversity, land use mixing is considered one of the key factors in reducing carbon emissions, and when multiple functions such as employment, education, business and entertainment are gathered around residential areas, residents can meet their living needs in a short space radius, thereby greatly reducing their dependence on cars. Studies have shown that this multifunctional space design model is one of the most effective strategies to reduce carbon emissions. Through the design of high-density road networks and intersections, the higher the coverage and pedestrian accessibility of bus stops, which effectively improves residents' acceptance of green travel through design. One of the main reasons why

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residents living in the suburbs tend to have higher levels of carbon emissions is that their destinations are farther away from their destinations, and the distance between their settlements and urban centers or major employment areas directly determines their commuting patterns, so the impact of destination accessibility on carbon emissions is also crucial. As for the distance to the bus, it is reflected in the convenience of residents reaching the nearest bus stop, and the shorter the distance, the more likely residents are to choose public transportation to travel, thereby significantly reducing carbon emissions.The natural environment forms the origins and destinations of residents' travel, on which basis it provides the infrastructure for their travel behavior and CO2 emissions.

Nevertheless, a spatial perspective alone is not adequate for fully understanding the disparity of residents' travel behavior, and significant differences between socioeconomic characteristics demand attention. This is in line with the findings from numerous studies, which have found a positive relationship between income and travel-related carbon emissions, as individuals with higher household incomes are more likely to own cars and prefer cars for traveling.Carbon emitted by homebuyers vs. renters, too. Homeowners tend to travel in higher carbon-emitting patterns, reinforced by their greater financial resources, more than renters do, who are homebound both because they have fewer financial possibilities and transport opportunities.In addition, the education level, the occupation of a household, and the number of cars available all indirectly impact carbon emissions by shaping travel preferences. For instance, low-educated and unskilled workers are more likely to use public transportation and non-motorized travel; highly educated persons and top managers, when commuting between districts, do consume higher amounts of transport energy. These socioeconomic attributes are the source of residents' "travel capacity" and to some extent reinforce or attenuate the influence between the residential spatial environment and travel behavior.

In addition to objective conditions, residents' subjective perceptions and attitudes are important mediating factors influencing low-carbon travel. Kitamura et al.'s research shows that residents' satisfaction with the travel environment and their perceived safety and comfort of walking directly influence their willingness to give up car travel. Bagley and Mokhtarian further suggest that residents' lifestyle preferences, such as their emphasis on convenience or environmental awareness, often explain differences in travel behavior more than the objective spatial environment. This means that even if a residential area's spatial design provides good walking and public transportation facilities, if residents lack a green travel awareness, their ultimate carbon emissions may remain high. In other words, subjective perceptions serve as a bridge in the "space-behavior" chain, determining whether residents truly translate objective low-carbon environmental conditions into actual low-carbon behaviors. Ignoring this dimension is likely to overestimate the direct impact of physical space on travel behavior. Various housing estates share several common problems based on a comparative study. To start with, some (sub)urban areas suffer from the lack of an integrated transport system due to low road density and poor public transport accessibility, resulting in high car dependence. Second, a monotonous land use pattern results in the separation between residence and work/consumption places, driving residents to make longer journeys as more travel will be undertaken for daily activities. This increase in travel also leads to a rise in carbon emissions induced by transportation. Third, in some neighborhood spaces, there is not enough public green space and shared public spaces to make walking and slow-moving transportation inviting. Moreover, citizens do not have awareness of low-carbon trips, and small green transportation has not become the mainstream choice, indicating a need to promote environmental cognition. These problems not only intensify the consumption of transportation energy and carbon emissions but also, to some extent, present obstacles to the healthy growth of cities and sustainable habitats.

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3. Comparative study of development layout and travel carbon emissions applied to residential construction

Several cases have compared different types of housing development patterns and measured the carbon emission amount generated from residents' travel to supply the empirical basis for low-carbon living planning. In his research on residential areas in Shanghai, Wang found that residential areas with multi-story enclosed and low-rise row-type layouts have significantly lower per capita carbon emissions than low-density, dispersed residential areas. This layout can effectively shorten residents' walking distance, increase the use of public transportation, and thus reduce the frequency of car travel. In addition, Huang's research on Wuhan shows that for every 1 km/km² increase in road network density, residents' travel carbon emissions decrease by an average of about 5%, highlighting the key role of internal road connectivity and intersection density in green travel. These studies all show that residential spatial form has a direct and significant impact on residents' travel behavior and carbon emission levels. High road network density and reasonable spatial layout can alleviate residents' dependence on private cars to a certain extent.

In a micro case study of Mianyang residential area in Sichuan, a more intuitive comparison of carbon emissions from different types of communities is conducted. According to the data, the closed community "Galaxy Bay Garden" has a weekly commuting carbon emission of 424519 g due to its single function and sparse road network; The open block "Wulidui Community" has a high road network density and mixed functions, with a weekly carbon emission of only 32,696 g, a difference of more than ten time. Open blocks can increase the attractiveness of walking and cycling to a certain extent, and further reduce commuting carbon emissions. The study also found that there is a large carbon emission gap between different commuting modes, and the carbon emission of walking is the lowest carbon emission. Private cars, taxis and other high-carbon emission and long-distance travel vehicles have a maximum carbon emission of 417,575g. At the same time, the results of the study are also in line with the "60/20" carbon emission rule, that is, 60% of carbon emissions come from 20% of high-carbon travelers. This shows that the separation of work and housing is a key issue in carbon emission control, and optimizing the mix of residential functions, improving transportation accessibility, and improving the slow travel system are necessary means to reduce the proportion of people with high carbon emissions.

However, to optimize the shortcomings of existing living models, it is also necessary to find a balance between environmental benefits and different design goals such as living comfort and safety. High-density construction can shorten walking distances and increase the utilization rate of public transportation, but it may also cause problems such as noise, insufficient lighting, overloaded public facilities, and crowded community space, affecting the quality of living. While reducing carbon emissions, the integrated utilization of land also poses a challenge to the refinement of design and management strategies, because it is necessary to deal with possible conflicts between commercial and residential functions and insufficient public service support. Open blocks have a positive guiding effect on low-carbon commuting, but they also need to respond to citizens' concerns about privacy and safety, and improve residents' safety perception and living experience through greenery, landscape walls, lighting and other designs.

4. Strategies for optimizing low-carbon residential environments

This study proposes optimization strategies from multiple dimensions such as urban planning, transportation, public facilities, green space systems and national action. In terms of land use, to improve the diversity of facilities within the unit's space, commercial, educational, medical and

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cultural and entertainment facilities should be reasonably laid out near residential areas according to residents' daily needs to achieve a close coupling of residential, work and leisure functions. Allow residents' various needs to be met within a relatively close travel distance, and they tend to choose low-carbon travel methods such as walking and buses. From the perspective of road systems, the road network density and intersection density should be appropriately improved to enhance the connectivity of road systems in the living circle and support the operation of multi-level public transportation systems. However, special attention should be paid to avoid traffic congestion caused by excessive high density. At the same time, optimize the travel environment and design diversified access paths for different residents such as the elderly, students and office workers to create a safe, convenient and comfortable slow-moving transportation network.

For public transportation facilities, layout optimization is carried out to improve the accessibility of public transportation, and to shorten the distance between the bus stop and the residential area as much as possible under the premise of reasonableness. Try to shorten the distance between the bus stop and the residential area as much as possible within a reasonable range. Set up a multi-functional comprehensive transportation hub, integrate various transportation modes such as buses, subways and shared bicycles, and improve the convenience of transferring to public transportation and other low-carbon travel modes. It can combine smart transportation technology to provide residents with low-carbon travel route recommendations for "walking buses" or "cycling subway" through real-time traffic information, bus scheduling optimization and carbon emission monitoring.

In terms of green space planning, it provides residents with good walking and leisure space and promotes walking. Since the increase in road network density may lead to the entire land being cut, we can mainly use the layout of urban linear green space along both sides of the river to give full play to the advantages of high flexibility and wide coverage of linear space. Encourage the whole people to participate in low-carbon travel and advocate a healthy lifestyle. With the help of specific policies and incentive mechanisms, fill the gap in residents' cognition and behavior and create a new low-carbon, healthy and environmentally friendly fashion pursuit.

5. Conclusion

This study systematically discussed the mechanism of the spatial model of residential space on residents' travel carbon emissions, and analyzes the comprehensive influence mechanism of physical space environment, residents' socio-economic attributes and subjective perception factors, and the comprehensive impact mechanism on residents' travel carbon emissions based on typical residential cases and the "5D" built environment theory. The core mechanism of the open residential model of high-density development, mixed functions, and small blocks can significantly reduce residents' travel carbon emissions, and its core mechanism is to shorten the travel distance by optimizing the spatial layout, improve the convenience of walking and public transportation, and improve residents' acceptance of low-carbon travel methods. The open block gathers diversified living functions, and also increases the proportion of slow travel and bus travel through dense road network and high accessibility design, effectively reducing the dependence on private cars.

This study filled the theoretical gap in the "space-behavior-carbon emissions" chain of existing research, integrates the built-up environmental indicators and residents' subjective perception factors, and provides a more complete analytical framework. The study showed that relying solely on spatial design is not enough to ensure low-carbon travel, and residents' travel preferences, lifestyle and environmental awareness play an important role in practice. Most of the data in this study only conducted horizontal correlation analysis, and there was no longitudinal comparison to verify the causal relationship between spatial-perceptual-behavior, and the correlation analysis

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between microspatial elements (such as street interfaces and green space layout) and residents' mental health and travel experience was not in-depth enough. In the future, a multidisciplinary system analysis framework can be built at the theoretical level, and big data and other methods can be used to dynamically track data at the methodological level, and the research results can be transformed into quantifiable and actionable low-carbon settlement planning guidelines at the practical level to support the green transformation of cities and the realization of sustainable development goals.

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