Urban surface modeling using town energy balance model: a review

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Abstract. In recent years, the Town Energy Balance (TEB) model has been used constantly to simulate energy exchanges in urban areas. This work is based on a systematic literature review of scientific publications in relation with the application of the TEB model in various climatic conditions and urban morphologies. The selected studies were analysed according to many criteria such as their objectives, input parameters, model configurations, and evaluation techniques. The TEB model has been integrated in numerous studies to simulate temperatures and energy between surfaces and the atmosphere in cities. It also contributes to the study of solutions such as green roofs, reflective materials, and plants to reduce heat islands in urban areas. Still the model needs very detailed urban data base and it requires adaptation for each city. As a result, the TEB model is useful to understand the form of cities and the impact of green solutions in the energy in urban scale. However, the model still needs improvement with both energy and water. This study gives a clear summary of the TEB model and still the suitable tool for planning sustainable and climate-friendly cities.

1 Introduction

Cities are responsible for more than 70% of global energy consumption and climate change is their principal issue [1][2]. Since the growth of urban populations and infrastructure expands, modelling the energy exchange was very important in urban scale. This helps in designing urban environments that are both sustainable and resilient. Accurately simulating the surface energy balance in cities is key to understanding how heat builds up, how temperatures are distributed, and how effective different climate solutions are[1][2].
The most frequently used tool for this purpose is the Town Energy Balance (TEB) model. By considering the thermal and radiative parameters of urban surfaces, it models energy flows in the urban atmosphere [3].

The impact of various forms of urban design and thermal comfort have been the subject of several studies conducted in Morocco using various models and software, including ENVI-met. For instance, one study looked at how open urban layouts affect outdoor comfort in various Moroccan climates, while another study conducted in Rabat discovered that mixed urban forms were the most effective at reducing heat stress[4][5].

This paper presents a systematic review of reseach that used the TEB model between 2015 -2025. The paper identifies the TEB model's primary advantages and disadvantages and

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explores possibilities for improvement through the analysis of a few chosen case studies. The goal is to support climate researchers and urban planners in solving issues related to sustainable energy use and urban heat.

Until now, the TEB model has been extensively applied in many climates and areas to examine urban heat islands, evaluate climate solutions, and enhance urban climate simulations. But even with its widespread use, it still has certain limitations. These include the need for a lot of data, calibration issues, and a lack of models for the interaction between water and energy [3][6].

2 Research Methodology

This study is based on a systematic review of peer-reviewed articles and review papers that used the Town Energy Balance model in urban climate research. The ScienceDirect and Scopus databases were the primary tools used for the literature search, which looked at works published between 2015 and 2025. Using Boolean operators [7], the following keywords were chosen in various combinations: "Town Energy Balance" OR "TEB" AND "Urban Surface Modeling" OR "Urban Canopy Model" AND "Urban Climate" OR "Urban Energy Balance." Finding research that explicitly used the TEB model to assess climate strategies, examine energy flows, or simulate urban temperatures was the aim.

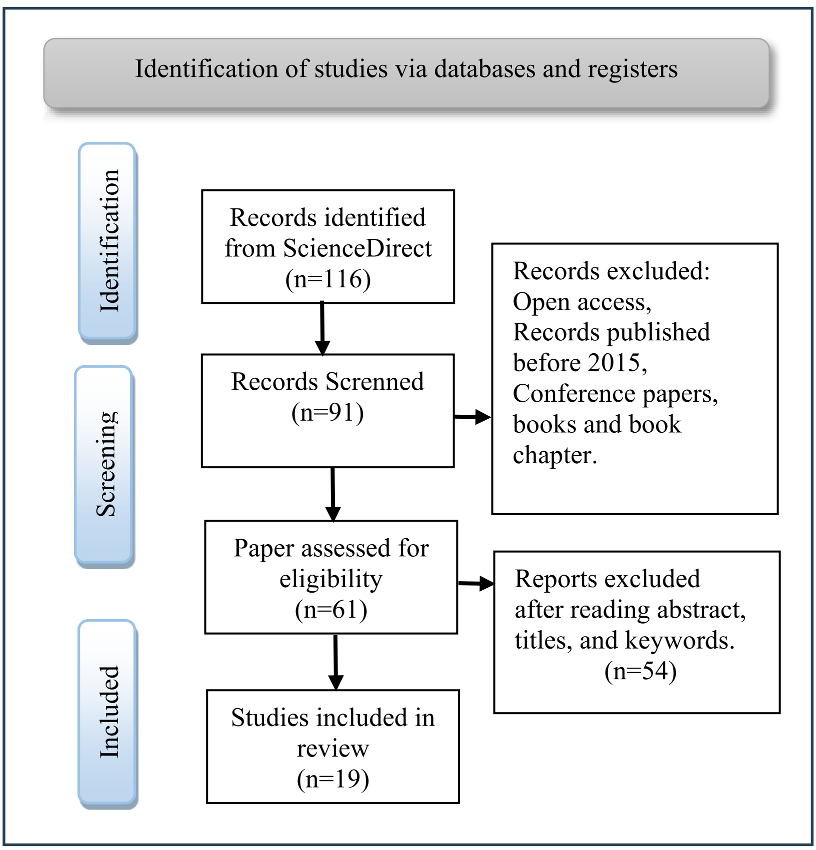

Fig 1: Prisma flow diagram for updates systematic reviews which included searches of databases and registers [8]

The search initially turned up 116 entries, as seen in Figure 1. 91 publications remained after open-access papers, research published before 2015, and non-peer-reviewed sources (e.g., books, conference papers, and book chapters) were eliminated. 61 articles were then subjected to a more thorough evaluation based on their titles, abstracts, and keywords. 7 of these papers were selected for additional analysis after meeting all selection criteria.

Each article had to cover several urban design and climate zone types, properly explain the methodologies used, and use the TEB model in simulations that focused on energy or climate at the urban scale in order to be included. This contained details on the input data, model configuration, and validation procedures. Studies that only used theoretical references to TEB or lacked explicit methodology were excluded. The analysis examined the research objectives, urban context, model setup, data sources, validation technique (e.g., comparing results with actual observations), and key findings for each chosen study. Particular focus was placed on the application of the TEB model inside the larger simulation methodology.

3 Results

3.1 Key Studies on the TEB Model

An overview of significant studies that applied the Town Energy Balance (TEB) model for a range of research objectives and in diverse regions of the world is provided in Table 1. It demonstrates how the model has been applied to various purposes, such as examining the impact of vegetation on thermal comfort in urban areas like Paris or demonstrating how ma chine learning may speed up simulations.The table also demonstrates the adaptation of the TEB model to the study of Moroccan street geometry, water related processes in green urban areas, and enhacements to the representation of solar radiation and temperature in European cities. The review only considered research that included through setup details and trustworthy testing.

Table 1: TEB Model Applications Summary.

	Study Area / Topic	Application	Reference
1	Global (various climates)	Use of TEB across temperate, arid, and tropical climates	[9]
2	Paris	Evaluate the cooling effect of trees and green spaces using new vegetation modules	[6]
3	London and Toulouse	Coupled with the SPARTACUS-Urban radiation model to simulate shading and longwave radiation trapping more accurately	[10]
4	Morocco (Fez,Agadir, Errachidia)	Assess street canyon geometry and thermal comfort	[11]
5	Machine Learning (Global)	Emulate TEB outputs such as heat flux and temperature profiles, significantly reducing simulation time	[12]

6	Vegetated Urban areas (Europe)	Enhance hydrological processes in TEB-Veg for better simulation of water–energy exchanges	[13]
7	Neighborhood scale (Europe)	Used detailed vegetation mapping to improve TEB simulations for local microclimatic analysis	[14]

3.2 Strengths and Limitations of the TEB Model

The key strenghts, weaknesses, and limitations of the research that applied the TEB model are summarized in Table 2. Every example demonstrates how the model was applied in various contexts, highlighting both its continuous issues such as the requirement for a vast amount of data and the challenges of applying it in big or complex urban areas and its improvements, such as improved plant modeling and the application of machine learning.

Table 2: Overview of Key TEB Studies: Strengths, Weaknesses, and Limitations.

	Strengths	Weaknesses	Limitations
1	Covers diverse climates and shows TEB in mesoscale models	Lacks detail on how TEB performs alone	Trend-focused that technically deep
2	Enhanced TEB with a vegetation module to simulate tree effects on comfort in Paris	Focuses only on one city	Does not combine trees with geometry or anthropogenic heat in the analysis.
3	Improves radiation modeling, validated the model in London and Toulouse	Increased computational cost	Tested in a few locations
4	Study how Street geometry affect thermal comfort	Local data limits wider applicability	No vegetation or human heat sources
5	Accelerates TEB outputs with Machine learning	Depends on quality of training data	Lacks in physical explanations ,may need retraining
6	Improves hydrological realism in TEB (runoff, infiltration, soil evaporation) Validated with observational data from real sites	Focused mainly on vegetated surfaces Complexity increases for urban areas without vegetation	Limited evaluation in dense urban geometries Does not include full anthropogenic water use (e.g., irrigation, domestic)

7	Integrates high-resolution vegetation mapping into TEB Improves representation of vegetation in urban climate simulation	Focuses on a specific neighborhood scale Relies heavily on detailed geospatial data availability	Limited scalability to larger or more heterogeneous urban zones May not reflect anthropogenic influences or rapid land use change

4 Discussion

The Town Energy Balance model is a flexible and expanding tool in urban climate research, as demonstrated by the comparison of significant studies in Tables 1 and 2. It has been used to explore how local weather conditions are influenced by things like plants, street design, and solar radiation, as well as to model the flow of energy in cities in various climates, such as temperate, dry, and tropical.

The model was developed through improving radiation variables to simulate shading and longwave radiation trapping more accurately, as shown in a study that used a system such as SPARTACUS-Urban. Another study used machine learning to accelerate simulation time .

There are still some issues facing this model such as high cost of computers, the need for local data, and the disregard for heat or water from human activity. Considering this significant improvement, they need to do more research to increase the accuracy of the model in various locations to help prevent global warming and climate change.

5 Conclusion

There is a huge interest in studying the urban microclimate in recent years, which explains the growing interest in the TEB model. It has been used in several places, climatic regions, and research topics. By comparing numerous studies, the model has been improved through modifications such as including machine learning techniques, radiation systems, and plant models.

The TEB model is still in development because of some gaps it was facing, for example, the lack of urban location data and the change of some parameters that impact the effectiveness of the methods used. All of that led to limiting the simulation accuracy.

To conclude, the TEB model needs more improvement in the context of water systems and city geometry, especially because of the complexity of the urban form. Otherwise, the model also needs to be improved in the context of changing parameters, to be more accurate and usable even when data are limited. The model also needs to be improved in representing heat and water from human activity. To reduce computation time and cost, the TEB model is combined with machine learning techniques, which gives good results in the end. By improving these aspects, the TEB model will be more useful for planners, making cities more resilient and sustainable.

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