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# Overview On The Role Of " Reduced-Order Bottom-Up Urban Building Energy Modeling Approach" In Energy And Environmental Improvement Studies

**IMED EDDINE KHELFA [1]*, YOUCEF LAZRI [2], RIAD TOUMI [3]**

[1] *Department of Architecture, and Hydraulic and civil engineering Laboratory (L.H.G.C), University 8 May 1945 – Guelma. PB 401, (24000), Algeria.*
*Email: Khelfa.imededdine@univ-guelma.dz*

[2] *Department of Architecture, and Hydraulic and civil engineering Laboratory (L.H.G.C), University 8 May 1945 – Guelma. PB 401, (24000), Algeria.*
*Email: lazri.youcef@univ-guelma.dz*

[3] *Department of sociology, University of August 20th, 1955, B.P.26 El-Hadaiek Road, Skikda, (21000), Algeria*
*Email: ri.toumi@univ-skikda.dz*

## Abstract

*To create more sustainable future, it is essential to design energy-efficient buildings and put in place an appropriate energy supply infrastructure. To determine the best solutions for reducing energy consumption and ecological footprints in urban contexts, decision-makers need evaluation criteria and potential scenarios. This paper is a literature review of the "reduced-order bottom-up approach to urban building energy modeling", which is one of the methods being implemented to achieve these goals. The study also provides an overview of simulation software tools based on this approach, their working methods and their contribution to the field of research related to improving the energy system in buildings, taking into account ecological, economic and social aspects. The study also showed the advantages of this approach which appear in ease of use, time saving, and accuracy in some cases, but it also disclosed many disadvantages, particularly by the presence of uncertainties in some cases where the scale of the study is large, and calibration will be more necessary, and at the same time more difficult.*

**Keywords:** *Urban Building Energy Modeling approach, Reduced-Order method, Energy efficiency, Environmental Improvement, IT simulation tools, literature review.*

## List of abbreviations

| | |
|---|---|
| *ASHRAE* | *American Society of Heating, Refrigerating and Air-Conditioning Engineers* |
| *BEM* | *Building Energy Modelling* |
| *BREEAM* | *Building Research Establishment Environmental Assessment Method* |
| *CASBEE* | *Comprehensive Assessment System for Built Environment Efficiency* |
| *CEA* | *City Energy Analyst* |
| *CEN* | *European Committee for Standardization* |
| *HQE* | *High Environmental Quality* |
| *HVAC* | *Heating, ventilation and air conditioning* |
| *ISO* | *International Organization for Standardization* |
| *LCA* | *Life Cycle Analysis* |
| *LEED* | *Leadership in Energy and Environmental Design* |
| *TEASER* | *Tool for Energy Analysis and Simulation for Efficient Retrofit* |
| *UBEM* | *Urban Building Energy Modelling* |

[1]* khelfa.imededdine@univ-guelma.dz (corresponding author)

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## 1-Introduction

Energy is a necessary resource for human survival and economic growth. It has attracted worldwide interest in recent decades, and its use has spread to many sectors, rapidly and on a massive scale. However, this rapid progress has come at the price of depleting fossil energy resources and a more obvious environmental impact, as energy is produced, transported and used in a variety of ways that result in waste, discharges and numerous contaminants in soil, water and air. Also, more than two-thirds of the world's population is expected to live in cities by 2050, and each region of the world has a varying level of urbanization. In 2018, North America (where 82% of the population lives in urban areas), Latin America and the Caribbean (81%), Europe (74%) and Oceania (68%) are the most urbanized regions. Asia's urbanization rate is currently very close to 50%. In comparison, Africa has a population residing in urban areas at a rate of 43% (United Nations, 2018). Urbanization and the different needs of buildings users have contributed significantly to global energy consumption, with the residential sector alone accounting for 26.6% of electricity consumption and 29.7% of natural gas consumption in 2019, according to IEA statistics (2021), as shown in figure (1).

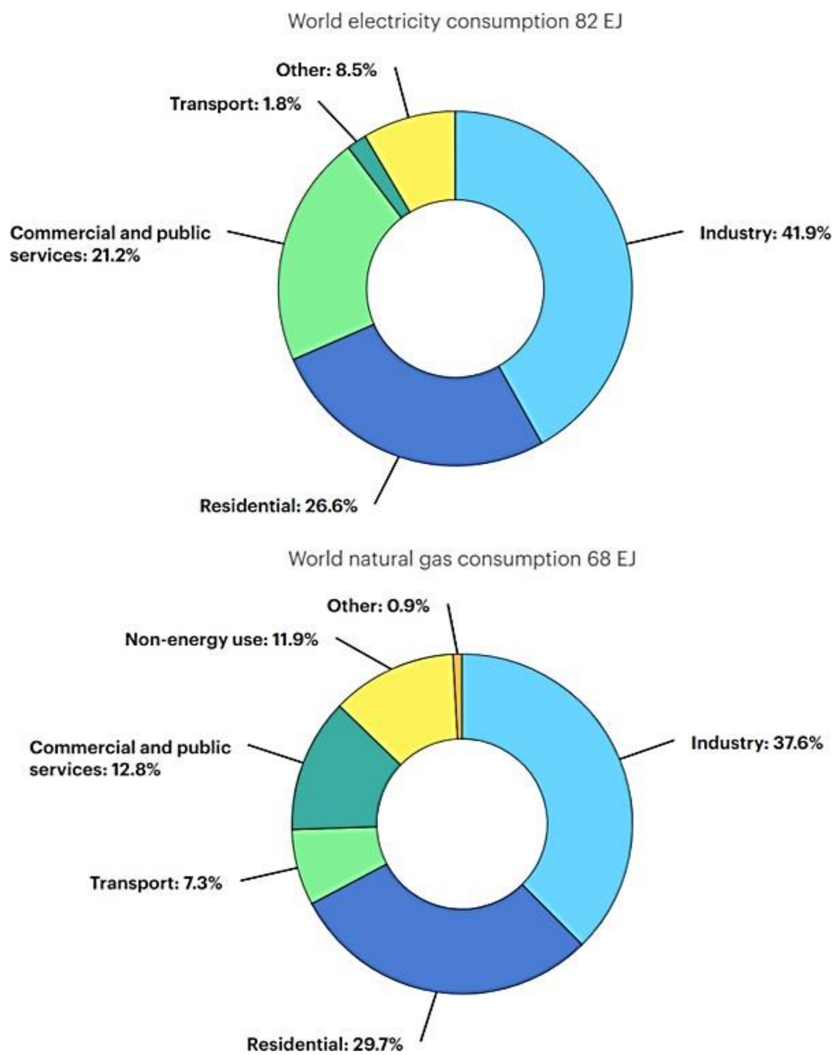


**Figure N° 01:** The worldwide electricity and natural gas consumption in the different sector in the year (2019). Source: (IEA, 2021).


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Furthermore, on the basis of 2022 statistics, and as shown in figure (2), operational uses of buildings were responsible for 27% (9.9 GT) of global greenhouse gas emissions, while the building construction industry contributed with 6% (2.3 GT), and other construction industries with 7% (2, 4 GT), according to (architecture2030 website, 2022), meaning that there is a significant opportunity to reduce energy consumption and associated greenhouse gas emissions, given that the construction industry is at the center of energy supply and demand in cities. Implementing energy efficiency legislation and awareness-raising initiatives can help achieve these reductions.

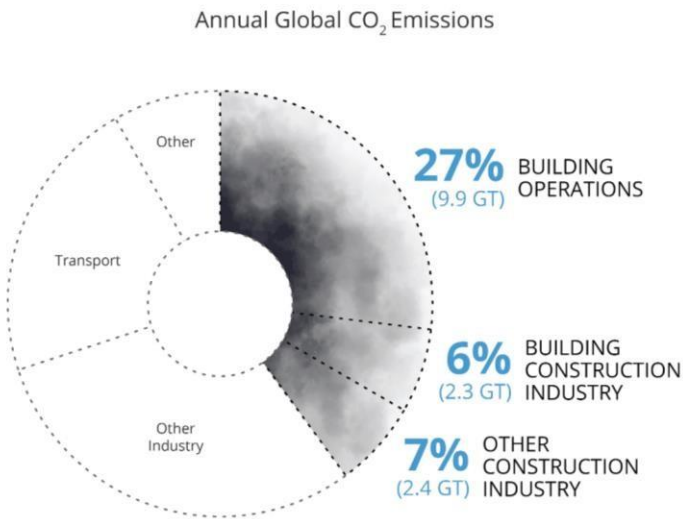


**Figure N° 02:** the percentage of contribution of buildings operations and construction industries in the annual worldwide CO2 emissions (2022).
Source: (architecture2030 website, 2022).

Numerous energy and environmental labels for buildings and cities have emerged over the last three decades, and are seen as a sign of quality, with the aim of achieving a better level of energy and ecological performance, based on a public technical reference system, and put into practice on a voluntary basis. Labels are linked to the urban development process and to the programming, design, construction, rehabilitation and operation of structures. Given the large number of labels available worldwide (Carassus, 2016), the first was created in the UK in 1990 with the launch of (BREEAM), a multi-criteria instrument, according to (Reed et al., 2009). Other grading methods have appeared in various countries, some of which concentrate on energy whereas other methods take a more comprehensive approach to sustainability (Sayce et al., 2010). For instance, the 1990s saw the introduction of the US Energy Star (energy), the HQE label in France (multi-criteria), as well as the Swiss Minergie (energy) label. The (LEED) program in the United States, the Green Globe program in Canada, Green Star in Australia, along

with (CASBEE) in the country of Japan were among the several multi-criteria programs that were introduced in the course of the 2000s (Directorate-General for Energy, 2013).

For the same purpose, and in the scientific research field, many methods and approaches were appeared in the last years, some of them are depending on energy simulation models, which may be used to examine and improve various design options for a building's energy efficiency.

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For a number of energy-related uses, including planning, calculating energy demands and potential, analyzing retrofits, forecasting, assessing the effect of green energies, and lowering greenhouse gas emissions, several energy simulation models were developed (Jebaraj & Iniyan, 2006; Torabi Moghadam et al., 2017).

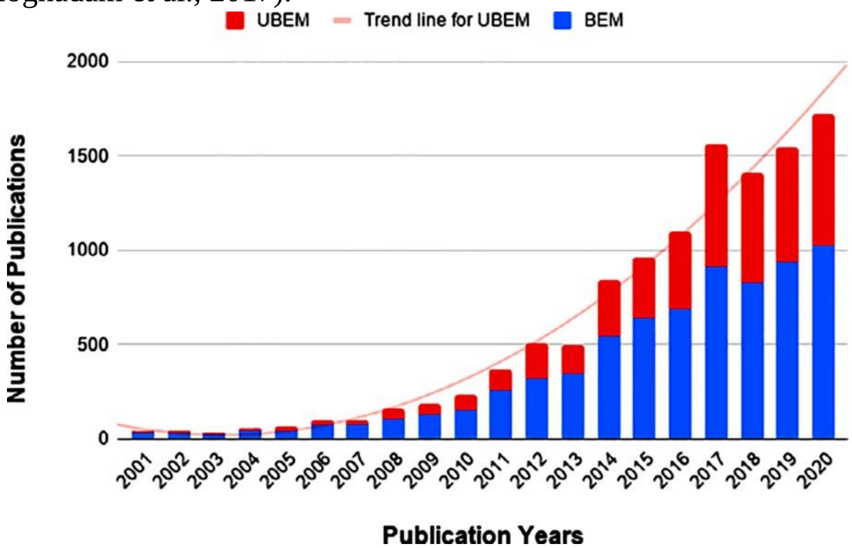


**Figure N° 03:** From the World of Science academic search platform, BEM as well as UBEM publications are on increasing numbers.
Source: (Ali et al., 2021).

Depending on the scale of the study, energy modelling can be carried out at architectural (BEM) or urban (UBEM) level, observing that between 2011 and 2019, the trend for BEM and UBEM articles has steadily increased, as shown in figure (3), noting that UBEM articles started recently and in smaller quantities than BEM studies, but that both are steadily increasing due to the great need and interest in improving energy quality and ecology in the building and urban sectors.

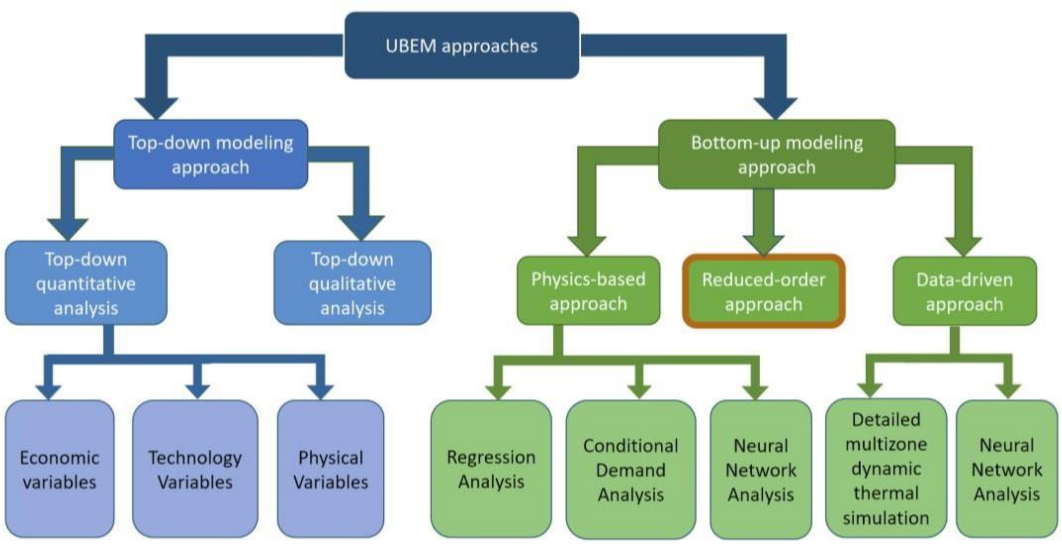


**Figure N° 04:** Schematic of the UBEM approaches.
Source: Author 2023

UBEM therefore requires even more attention, as it is a relatively new field, covering large geographical scales, as well as vast scenarios and improvement systems.

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As shown in figure (4), UBEM comprises numerous approaches, top-down and bottom-up modeling approaches, which in turn contain other sorts of approach.

The aim of this article is to identify one of the Botton-up approaches used in the UBEM research field, and which is called "Reduced-order bottom-up Urban Building Energy Modeling approach", choosing to have more details on its properties, method of use, tools, as well as its advantages and disadvantages. The aim is also to extract its degree of efficiency and contribution in the research field of urban energy and environmental improvement through the analysis of numerous previous studies based on this approach.

## 2- Methodology

This article is a systematic literature review that aims to identify the "Reduced-order bottom-up Urban Building Energy Modeling" approach, based on information from various articles in prestigious scientific journals, which have occupied research in the field of energy, ecology, urban building energy modeling, and in particular those that have used reduced-order simulation tools, highlighting its contribution to energy planning and improvement in the urban sector.

The research begins by defining the approach, comparing and identifying the main tools, then explaining the method of using these tools, before analyzing 12 examples of their use, and finally determining their advantages and disadvantages.

## 3- Results and discussion

### 3-1- Reduced-order approach

Reduced order models (ROMs) are high-fidelity, sophisticated models that have been simplified. They reflect the behavior of various source models in order that engineers may swiftly investigate the dominant impacts of a system with little computational resources.

Because of market expectations for faster design cycles that yield higher quality goods, ROMs have grown in popularity in the product growth and development business (Kulp, 2019).

This type of approaches is frequently used for rapidly evaluating the energy efficiency of buildings. Compared to the physics-based as well as data-driven techniques, these approaches need less inputs (Hong et al., 2020).

The identification of model values for parameters, which might be approximated by applying different calculation standards published by the (CEN) and the (ISO), is one of the procedures unique to this technique. Through a series of normative declarations that include the physical building characteristics and the accompanying systems for various building types, these standard procedures specify the calculating process. The influence of heat transport and thermal dynamics via the building envelope on inside temperature is described by ASHRAE's guideline thermal network framework (ASHRAE, 2021).

### 3-2- Reduced-order tools

Frequently used programs that based on reduced-order approaches, are SimStadt, CEA, TEASER, as well as OpenIDEAS. These different tools have many common points, like they have numerous differences between them, as it’s displayed in table (1), which conclude information about each tool, beside its supported inputs as well as its outputs, on the basis of many resources, like (Baetens et al., 2015; NOUVEL et al., 2015; Fonseca et al., 2016; Remmen et al., 2018; Ferrando et al., 2020).

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**Table N° 01:** Comparison between the main tools which are based on reduced-order approach.
Source: Author 2023.

| **Tool** | | **SimStadt** | **OpenIDEAS** | **CEA** | **TEASER** |
|---|---|---|---|---|---|
| **Year** | | 2013 | 2015 | 2016 | 2018 |
| **Developer** | | University of Stuttgart, Germany. | Katholieke Universiteit Leuven, Germany. | ETH Zürich (Switzerland) and Singapore. | RWTH Aachen University, Germany. |
| **Availability** | | No public release | Free public use | Free public use | Free public use |
| **Structure** | | Energy analysis is carried out using ISO 13,790 and the estimated solar potential using online databases like PVGIS or meteorological data like METEONORM, for instance. | Systems (MODELICA IDEAS library), stochastic residential occupancy behavior (Python StROBe), and building modeling (Modelica FastBuildings library in addition to GreyBox) make up the first two components. | There are six modules (demand, resource potential, network technology, supply infrastructure, decision, as well as assessment) and seven data sets (weather, urban environment, energy providers, conversion, distribution, systems, and targets). | There are three primary packages: the data package (which enables data input and output reading), the logic package (which aids in data processing), and the Graphical User Interface package. |
| **Inputs** | | | | | |
| | Supported data format | Geographic Information System+ CityGML. | Modelica + Python. | Geographic Information System+ CityGML+ Python. | CityGML+ Modelica + Python. |
| | Archetype supported properties | Envelop, systems, energy use, deterministic occupancy. | Envelop, systems, energy use. | Envelop, systems, energy use, deterministic occupancy, intended use, year of construction, building typology, deterministic or stochastic occupancy schedules. | Envelop, systems, volume, deterministic occupancy, intended use, year of construction, building typology, deterministic or stochastic occupancy schedules. |
| **Outputs** | | | | | |
| | Output display | Spreadsheet, and graphic visualization. | Spreadsheet. | Spreadsheet, and graphic visualization. | Spreadsheet. |
| | Building energy use | HVAC, hot water, electricity. | HVAC, hot water, electricity. | HVAC, hot water, electricity. | HVAC, hot water, electricity. |
| | Solar potential estimation | Only on roofs. | No solar potential estimation. | On roofs and walls. | No solar potential estimation. |
| | Urban energy systems | No urban energy systems. | District heating and cooling, Electric grid, Energy storages. | District heating and cooling, Electric grid, Energy storages. | District heating and cooling, Electric grid, Energy storages. |
| | Large scale general evaluations | Scenarios, life cycle analysis. | No large-scale evaluations. | Scenarios, life cycle analysis, benchmarking, food, cost-benefit analysis, transport. | No large-scale Evaluations. |
| | Time resolution | Yearly. | Minute, hour, day, month, year. | Hour, day, month, year. | Hour, day, month, year. |
| | Spatial resolution | Single building. | Single or group of buildings. | Single or group of buildings. | Single or group of buildings. |

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Initial observations on the data presented in the table above show that most of the tools used for this approach are developed by German universities, with the exception of the recent CEA tool, which was developed in the neighboring country of Switzerland, at ETH Zurich University, in collaboration with its Singapore center thereafter, demonstrating the great interest of this region in the development of this field.

The first appearance of this type of tools took place in this last decade, demonstrating its novelty, and its development continues, seeing that supported inputs and outputs are in increasing, what may lead to greater precision and more results, and in turn provides greater ease of analysis, and more angles of study.

Over the years, these tools have gone beyond the energy analysis of the building or urban ensemble, and have also enabled life-cycle analysis, solar analysis, as well as the economic aspect, taking into account construction phase needs as well as building use, according to different time resolutions.

In addition to passive and active architectural systems, UBEM's reduced-order tools are equipped, particularly in the latest tools developed, with urban energy systems, such as district heating and cooling, the power grid and energy storage.

**3-3- The method of use of these tools**

According to the previous comparison between the tools, the CEA is the software which touches all the aspects mentioned above, it makes it possible to cover several spatial and temporal scales, and facilitate the representation of the results through graphs. For this, it is favorable in this part to take CEA as a sample to explain the working method of this type of tools. It is one of the earliest open-source attempts of computing tools for the construction of low-carbon as well as highly efficient cities, a platform for urban building simulation. In a single simulation platform, the CEA integrates expertise in energy systems engineering and urban planning. This makes it possible to analyze the impacts, compromises, and synergies of various urban design concepts and energy infrastructure ideas. CEA enable professionals and academics to design next low- carbon cities (CEA official website, n.d.).

The (figure 5), which recapitulate the method of use of this tool, showed that the database and various inputs, including zone, district, topography, and weather, must be picked when a new project is started since these are crucial for the commencement and requesting of geospatial data. Whereas user files can be input in EPW format, the application only provides a small selection of weather files for some locations, but also, the user could import climate data, from other software, like METEONORM. A map that gives the option to pick the district to be looked at is then displayed. Buildings in this region can be automatically identified by CEA using its built-in identification capabilities, at which point they are prepared for editing (Jepsen et al., 2022).

The CEA provides standard databases on occupation schedules, loads of internal energy, indoor comfort variables, structure systems, envelope construction systems, as well as supply systems depending on building stock archetype data that offer energy demand predictions for simply unknown town quarters with no need of accessibility to specific construction or building detailed plans, as well as building system properties.


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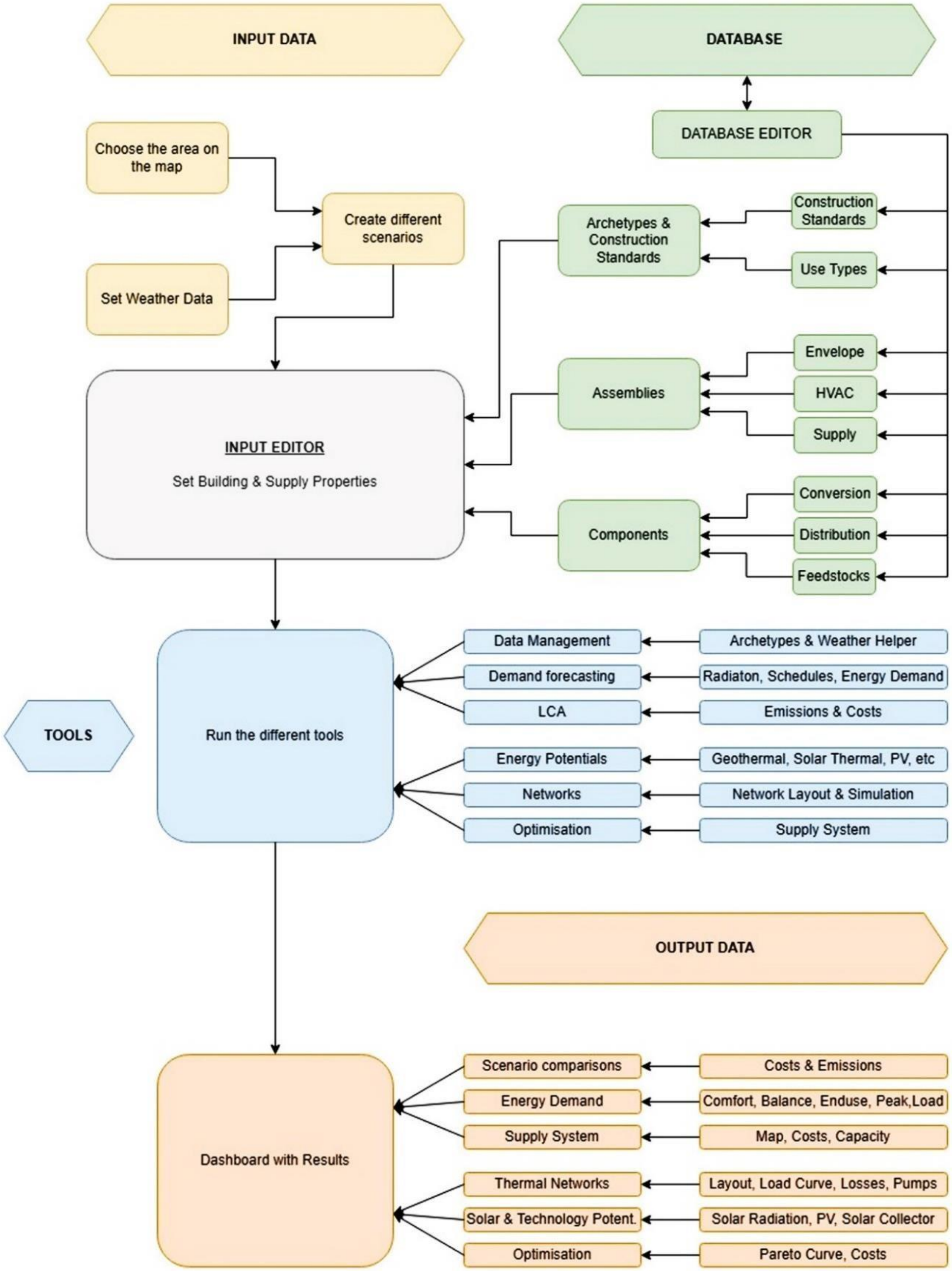


**Figure N° 05:** Schematic representation of the mode of use of the CEA tool
Source: (Jepsen et al., 2022).

Only general information about the building dimensions (such as the surface, the number of floors along with heights), construction period as well as refurbishment years(s), building system typologies, and the primary building purpose are needed to relate the archetype information to the specific building (Willmann et al., 2019).

Once all the necessary databases have been entered and the required data imported, numerous scripts need to be run, depending on the requirements and objectives of the study. These relate to many aspects, including data management, demand forecasting, lifecycle assessment, energy potentials, as well as energy networks and optimization.
The results were obtained in form of spreadsheets, and displayed graphicly in a dashboard within the tool, the presentations are including scenario comparisons, energy demand, supply system, thermal networks, solar and technology potentials, as well as optimization.

### 3-4- The contribution of the UBEM reduced-order tools in energy and ecological field

To get a clearer idea of the use of these tools in the analysis and energy and environmental improvement of buildings and urban areas, Table (2) summarizes the analysis of 12 articles and the main conclusions.

**Table N° 02:** summaries of some research papers that have used UBEM's reduced-order approach and tools. Source: Author 2023.

| Researches | Used tool | Study objectives | Main findings |
|---|---|---|---|
| (Baetens et al., 2015) | OpenIDEAS | IDEAS, StROBe, FastBuildings, and GreyBox1 are the components of the OpenIDEAS structure, which was developed for incorporated district simulations of energy. This framework enables quick prototype development for the design alongside running of district energy as well as manage systems. In addition to outlining the applied software design standards, the library architecture, and sample research findings based on the offered framework, the research has gone through the key criteria for establishing this structure. | Because of OpenIDEAS's innovative methodology, it is possible to investigate the interdependence of electric along with thermal (building as well as district energy) models in just one simulation model. The estimation of the aleatory unknown variables in the proposed approach is made possible by the use of stochastic housing occupant behavior for all commodities taken into consideration, whereas the computer simulation of centralized as well as decentralized algorithmic controls in neighborhood energy systems is made possible by the utilization of a large single model. |
| (Mosteiro-Romero et al., 2017) | CEA | The sensitivity study of architectural characteristics (window-to-wall ratio, occupant density, and envelope leakiness), thermal characteristics (U-values, G-values, thermal mass, as well as emissivity of construction surfaces), operational factors (set-point temperatures, ventilation rates), alongside internal loads (heat gains from occupants, appliance use, as | The approach presented in this research sheds light on the variables most crucial for CEA models, according to various building typologies as well as occupancy types in terms of heating and cooling requirements. The findings highlight the scale's most sensitive characteristics and offer crucial inputs for calibrating models so that urban demand predictions may be made with precision. |

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| | | well as lighting), is presented in this work. Regarding this, the research includes Saltelli's adaptation of the Sobol approach, the City Energy Analyst, and a two-step sensitivity analysis procedure. The case study area, which consists of 284 buildings with mostly educational, medical, and residential functions, is located in the heart of Zurich, Switzerland. | Seasonal fluctuations, occupancy types, building shapes and sizes, and geographical distribution were all taken into account throughout the investigation. |
| (Happle et al., 2017) | CEA | This study compares a model built around wind pressure in addition to air temperature with a constant air change rate model to see how the impact of each technique on a neighborhood's cooling and heating requirements differs. Using the CEA urban energy simulation tool, a case study in Switzerland with 24 buildings serving a variety of functions is simulated. | The findings show that an established infiltration rate model may be adequate for preliminary design investigations into district energy management systems, despite the significant variances for individual constructions, as the influence on system scale is still rather minimal. This analysis helps to further promote the creation of accurate and quick computer models of urban energy. |
| (Monien et al., 2017) | SimStadt | In the context of the investigation about project WeBest, in which six building styles representing the most significant architectural periods were examined, a case study within the German city of Essen was selected. The heat demand is calculated at both the single- building size as well as the city district scale using the urban simulation program SimStadt, which is based on three-dimensional urban geometry. The outcomes of each building type are compared with those of the dynamic building simulation program TRNSYS, which is used in industry. | The findings show that building model preparation and transfer to TRNSYS took a lot of time, whereas the SimStadt procedure is totally automated. The SimStadt findings were compared with overall consumption data at the district level. According to the analysis, heat demand forecasting using the SimStadt urban simulation platform, which is based on three-dimensional city algorithms along with construction databases as an indicator of the type of building and the period of construction, is appropriate for use with single buildings as well as town (district). |
| (Pajot et al., 2018) | TEASER | This study's objective is to estimate the electricity consumption flexibility potential of a structure. Research on a residential neighborhood has been completed as part of the European City-Zen project in order to develop effective load shedding orders. This new area, which consists of 23 buildings, is unique in that it has heating | This approach strikes a decent balance between the enriched model's accuracy and its longer setup time as compared to the simple model. Dynamic thermal modeling is particularly interesting in this context because it allows to track changes in operational temperature while also accounting for the physical reaction of structures and how quickly they respond. The use of carefully |

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| | | provided by heat pumps. The results of the GreenLys project and research conducted by RTE (electricity transmission network) were used to develop typical heat consumption patterns for load shedding situations in the first study case. This approach was also compared with research that uses dynamic energetic simulation to account for the building's physical behavior. | chosen indicators, like the rate of postponement by time frame, the rate of energy savings by 11 p.m., the operating temperature, and the decrease in CO2 emissions, allows for a multiple analysis of the effects of a load-shedding functioning (peak decrease, energy savings, thermal comfort, as well as carbon dioxide footprint). |
| (Remmen et al., 2018) | TEASER | In order to create dynamic building performance simulation models for individual, changing thermal demand projections of buildings in large building stocks with limited information, the approach and structure of TEASER are presented in this work. Then, the structure and organization of the real Python packages are discussed, to explain essential design choices. The article concludes with an illustration of the tool's functionality using three use cases of various scales. | By showing three different use cases on the scale of buildings with a high data density, on the scale of neighborhoods with necessary building parameters (period of construction, geometry, as well as function), and on the scale of cities with very little data (only geometry), the results demonstrated the use as well as capability of TEASER. They demonstrate TEASER's potential as a totally scalable and adaptive UEM solution. The TEASER concept serves as a springboard for addressing issues with individual, dynamic construction models along with urban-scale simulation. It offers a platform and general technique for creating unique and dynamic simulation models of building performance for a number of buildings at an urban scale. The TEASER data enrichment for constructing physics capabilities will be combined with stochastic user behavior tools in future development. |
| (Steingrube et al., 2021) | SimStadt | The methodology presented in this study combines KomMod, a tool for energy system optimization, with SimStadt, a program that enables researchers to evaluate building heating requirements using 3D building models. By combining these two models with a revolutionary heat disaggregation algorithm, it is possible to investigate the best ways to heat urban areas, as well as the ideal distribution of centrally provided heat and the design of the supplying heating grid. Additionally, a cost- | The concept that has been put out is a useful tool for organizing the development of district heating systems in urban areas. The main advantage of this strategy is that all sectors are optimized in addition to the intended district heating grid configuration. This is accomplished by utilizing a model of the energy system that incorporates all demand sectors and identifies solutions to meet each sector's energy demand for the lowest feasible cost. Instead, two quick optimization algorithms—one accurate for heating grid layouts and the other heuristic for linear point-like |

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| | | optimal system for energy may include other demand sectors, such as cooling, in addition to the assessment study of the function of central heating. A high-density metropolitan area along with a low-density rural community are used to test the new framework. | energy systems—independently produce two solution curves that cross to provide features. The presented approach may be used to a broader region, such as the entire city, with appropriate computing time, and is not just confined to tiny building models. |
| (Orozco-Messana et al., 2021) | CEA | This study suggests a neighborhood-scale adaptive model methodology for a performance-based LCA assessment of urban regeneration options based on building construction techniques targeted at energy-efficient building performance. The suggested framework also specifies architectural alternatives and plans for a certain building infrastructure. The suggested framework is then assessed based on the findings of the LCA in order to compare the projected outcomes of LEED and BREEAM, two building certification programs. | The approach described in this work has shown how to create an accurate digital representation of a neighborhood for assessing its LCA as assessed by the carbon footprint in a resource-efficient manner. The work may be connected to commercial tools for budgeting even though the database filled with all the information of construction solutions linked to building classifications as well as subsystems requires previous extensive knowledge of materials and procedures per region and time. |
| (Gorzalka et al., 2021) | TEASER | UBEM data collection and simulation tools are applied to a single building in this study with the aim of giving knowledge for specific retrofits. It makes use of precise geometry data that can be acquired using unmanned aerial vehicles, demonstrates how the entire process can be completely automated, and forgoes several simplification stages that are frequently employed in automated model production at district and city size for the creation of the energy simulations model. In this manner, a dynamic energy simulation model may be created with little user input. A case study is presented in this study as the initial move towards validation. | The model that is produced may faithfully represent the interior air temperatures during artificial heating and cooling. The necessity of precise window characterizations is highlighted by sensitivity analysis, which also supports the adoption of a highly simple interior geometry. The approach is already very near to practical application and provides up an opportunity for rapidly estimating financial potential as well as energy savings after renovation. Uncertainties associated with the utilization of archetype U-values are determined by comparing various classifications, with best- alongside worst-case projections showing variations in before retrofit heat consumer demand of approximately twenty percent from the average. |

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|---|---|---|---|
| (Weiler et al., 2021) | SimStadt | For a city neighborhood of 65 buildings within the context of Mainz, Germany, SimStadt's ability to size centralized as well as decentralized heat supply solutions are expanded and evaluated in this research. A decentralized system that utilizes air-water heat pump technology is contrasted with a biomass-fired boiler along with an oil-fired auxiliary boiler as well as a heating network using technical and financial metrics. | This study demonstrates that, even with the limited input information available during an early project stage, simulations for a district's heating demand as well as heat supply alternatives may be done with adequate precision. However, it is crucial to get precise data on the condition of building renovations since the heat needs of existing structures have a significant impact on the size and functionality of heat supply networks. Depending on national legislation, economic, primary energy, and carbon dioxide indicators can be computed using these data. |
| (Shi et al., 2021) | CEA | This study offers a new typological approach for examining how solar energy consumption and urban planning interact. In contrast to prior research that have used typological methodologies, this study emphasizes both computational effectiveness as well as appropriateness to the vernacular situations. A case study of constructed urban form with varied combinations of block size, building patterns, floor area ratios, along with site coverage is used to develop typical vernacular block typologies. The assessment of these building geometries for solar energy penetration and the capital costs of the photovoltaic panels was based on CEA, in addition to Rhino/Grasshopper, using Singapore as a case study. | The sunlight penetration and related capital expenditures of the 18 block typologies are evaluated. The characteristics of block size, construction patterns, as well as building density all have an influence on the usage of solar energy on-site to varying degrees. Site coverage along with building pattern are next in terms of influence, with floor area ratio taking precedence. To determine the relationships between solar energy consumption and the possibilities for such urban design factors, analyses and discussions are expanded. These results may be used by urban planners to direct preliminary urban design for maximizing on-site solar energy at affordable capital costs. Early stages of urban planning should take into account renewable energy sources. Additionally, the cost-effectiveness in addition to embodied greenhouse gas emissions of the conversion technologies must be taken into consideration for the performance evaluation in addition to attaining a specific objective of renewable energy penetration. |

| | | | |
|---|---|---|---|
| (Santhanavanich et al., 2022) | SimStadt | This study assesses and contrasts several approaches, including the usage of SimStadt web-based applications, databases, and the OGC SensorThings API standard, for handling dynamic simulation outcomes of the 3D city model and display this information on the three-dimensional web-based smart city application. | To maximize the benefits of storing and visualizing the energy analysis data in the smart cities' application, it is recommended that the SimStadt API service for on-the-fly simulation as well as the SensorThings API for managing pre-simulated findings be integrated. |

The information summarized in the table shows that these tools are widely used in research into energy and thermal comfort, taking into account both ecological and economic aspects. They showed their capacities and their high performance in a wide range of methodologies, either on their own or in conjunction with other software packages, depending on the needs of the study. They are particularly recommended in building renovation planning, to guide preliminary urban design to maximize on-site renewable solar energy technics at affordable investment costs, taking into account embodied and operational greenhouse gas emissions, in order to evaluate and improve building and urban performance.

UBEM's reduced-order tools are used at the architectural scale, as well as at the urban scale, and can also cover the whole city, in addition to their ability to analyze different building types and forms (collective housing, individual housing, commercial buildings, hospitals, offices...), in different geographical and climate contexts.

In addition, these tools could be used in the field of smart technologies, alongside parametric studies related to the building envelope or energy supply systems, they also carry out studies on energy consumption and its interdependence with HVAC needs, as well as with solar penetration; or also sociological studies on users' behavior and occupancy rates.

### 3-5- The advantages and disadvantages of UBEM reduced-order approach

According to the literature reviewed, UBEM reduced-order tools offer many advantages over other tools used in the same field but based on other approaches, while at the same time presenting many disadvantages.

The reduced-order modeling technique provides a physical representation of the archetype while being computationally efficient. In addition, the procedure for formulating these models requires less data. Reduced-order models combine the simplified physical model of the building with a model identification procedure to determine the design parameters. The reduction of physical models minimizes the demand for training information sets and, consequently, computation time. When optimizing construction operations under various design scenarios, reduced-order energy models offer greater flexibility. This involves determining the implications of differences in building form right down to changes in material parameters.

A reduced-order model can also provide a data-driven model that could be used as a design tool.

Similarly, building energy models can be created quickly and accurately at multiple modeling levels using the reduced- order modeling technique. The pre- and post-consumption behaviors of the existing building stock can be assessed using these models. These tools enable the analysis of multiple scales, from the architectural to the city scale. They also make it easy to analyze numerous aspects, such as energy, ecology, user behavior and economics, thanks to their automatic graphic presentations. On the other hand, reduced-order models present a significant risk when it comes to dealing with the problem of over-fitting model parameters. When validating a model, it's often taken into account the match between predictions and measured data. The corresponding reduced-order model needs to be compensated by greater complexity at the equivalent level to account for improved building dynamics. To discover and optimize the balance between the number of variables and the required accuracy, reduced-order models also need to be further investigated.

Validating modeled consumption presents a serious challenge, as measured building energy consumption is often not available on a large scale. Furthermore, one of the main shortcomings is that non-linear factors or processes are often represented by linear relationships, thus increasing the degree of uncertainty. Although reduced-order building energy models have been widely deployed, their usefulness has often been limited to certain applications and users. In addition, given the uncertainty of model parameters, reduced-order approaches sometimes require extensive calibration using collected data, especially, in the case of urban large-scale simulation.

## 4- Conclusion

This study provides an overview of several UBEM tools that use a reduced-order approach. To begin with, we defined the technique before comparing and identifying the main tools used in this approach, then described how to use these tools, following with 12 examples of their use, and finally determining their advantages and disadvantages. The main conclusions can be drawn as follows:

- The reduced-order approach of UBEM and its tools are new to the field of urban building energy, their appearance has been clearer over the last decade, and the studies based on this approach and on the UBEM in general are increasingly numerous.

- Most of the tools based on the reduced-order approach have been developed at German universities, and are generally free and accessible to any researcher interested in the field, also, the latest developed tools are more technologically advanced than the pioneers, in terms of inputs and outputs, as well as software structure.

- These tools enable analysis on a variety of scales, on various time resolutions, whether architectural or urban, in small areas or even on a surface covering the whole city, and the analysis can cover energy, ecological, economic, social and even bioclimatic aspects; they could be used in different geographic and climatic context, for the study of any type of buildings, with different study methodologies and objectives.

- They can be used by experts to plan energy renovations, or even to design new buildings, or urban agglomerations, taking into account occupant behavior, intervention costs, carbon emissions, as well as the right choice of energy supply systems, those could be provided at building-scale or by district systems, which can be based on the solar analysis that is also provided by these tools.

- The use of this type of tools is simplified, and the number of inputs and databases to be entered is limited; at the same time, the results can be rich, and help to achieve a good analysis and study of the phenomenon, taking into account several aspects and angles.
- The use of these tools either alone, or in collaboration with other tools in several studies, has shown their performance, their efficiency in terms of time saving and accuracy, despite the different methodologies and the different objectives; their use has also shown several weaknesses which lead to certain uncertainty in the results, due to the small number of inputs, which does not help in certain cases, especially in large-scale studies, where calibration becomes very important. and at the same time very difficult.

The strong demand for energy improvement in the building sector, and the need for an energy transition to clean, renewable energies, have given the development of this type of approach a significant necessity and importance, where its continuous upgrading adds further value and finesse to the research, and helps to avoid uncertainties, with the aim of achieving correct planning renovation or new design works, and establishing a balance between the aspects that constitute a pillar of sustainable development, and ensuring energy sobriety and efficiency, without causing negative economic, ecological or social effects, or affecting the well-being of occupants.

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