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TOWARDS HIGH-PERFORMANCE FACADE DESIGN AN OPTIMIZATION APPROACH FOR ENERGY EFFICIENT RESIDENTIAL BUILDING

Ph.D. Thesis Booklet

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Pecs, Hungary
March 2020

1. RESEARCH AIM AND OBJECTIVES

Preserving the environment is the most important issue of today’s world in which human being has to reduce energy consumption. Over the last years, building energy efficiency has worldwide considerable interest from the experts and researchers, since buildings are the largest consumer of the final energy consumption.

During the last decade in Algeria, housing construction issues became one of the development priorities. Policies and strategies were set up to tackle the housing demand and to reorganize the sprawling slum areas, providing social houses for the low-income families, the design and the constructional techniques of these buildings, are operated with over-shorter project planning time, it is striving to minimize design costs, neglecting the climatic conditions in the design process. As a result, it has been reported that 37% of the overall energy consumption was attributed to residential buildings. Otherwise, the architectural facade design, technologies, and strategies, are the most significant contributors to the energy performance and the comfort parameters of the buildings. Thus, the main target of this research is investigating the possibilities of enhancing the building energy performance through the building facade components, as well as to present an optimization approach for the building facade design that seeks to provide occupants thermal, visual comfort and indoor air quality with minimum energy consumption. Besides, to provide an adaptive facade design to the local environment, the Algerian hot and dry climate zone was the study context of this research. To fulfill this aim, the following objectives have set:

1. Review current literature on the building facade research and applications to define the main impacting parameters on the inhabitants’ comfort and energy consumption.
2. Diagnose the current situation of the existing social housing in Algeria in terms of building energy efficiency.
3. Investigate and find the optimal interaction between the several facade components design, to balance thermal, visual comfort, and indoor air quality with less energy consumption.
4. Define the most important aspects of indoor comfort which are related to high building energy efficiency in the study context.
5. Develop design guidelines for the building facade in a hot and dry climate to optimize building energy efficiency with easily executable techniques for local builders/ context.

6. Determine recommendations considering the responsive facade design for helping the designers/architects to improve the energy performance in a hot arid climate in the early stage of designing.

2. CONCEPTUAL ANALYSIS

To concretize the concepts of the hypothesis and to fulfill the thesis's main goal; the conceptual analysis of this study is determined; it present on the one hand the facade design strategies and parameters and the other hand the building energy performance concept. they are transformed into observable and measurable indicators. All these variables are defined based on the literature, and the problematic of the study context. *See Figure.*

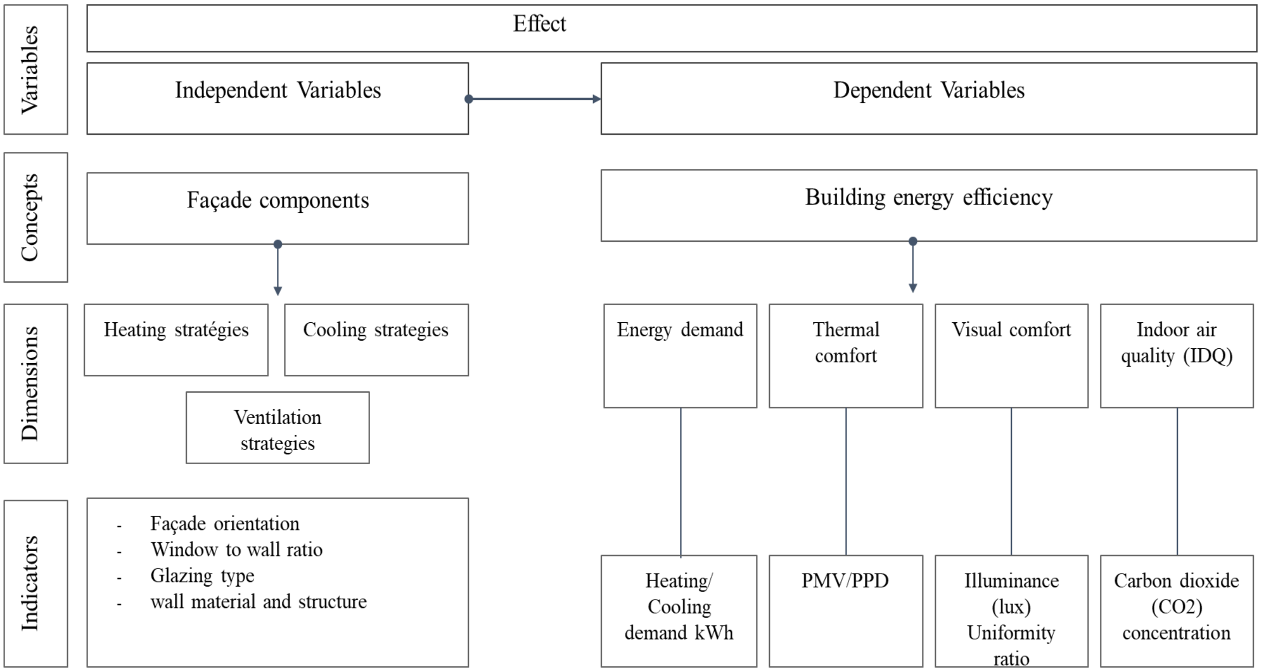

Figure 1: Conceptual framework of the research study

3. RESEARCH STRUCTURE OVERVIEW

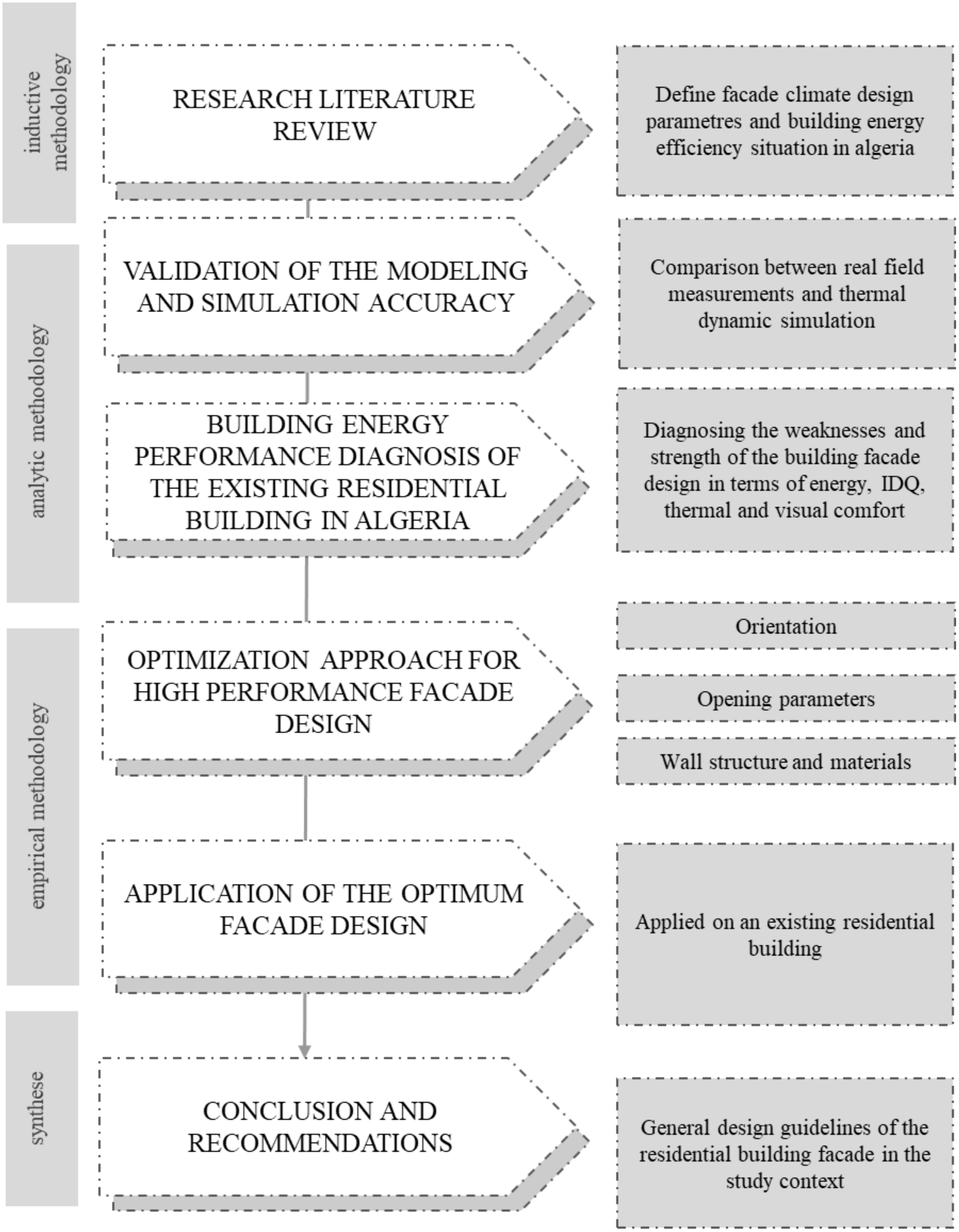

Figure 2: Research structure diagram for the topic

4. NEW SCIENTIFIC RESULTS

4.1 1st theory

The research methodology of this work is applied research its goal is to solve a real problem, it is deductive using quantitative and experimental methods. it is based on a quantitative evaluation using a thermal dynamic simulation through the free and open-source VI-Suite plugin that uses some built functionalities of Blender 3D software to control the external applications Energy plus and Radiance to conduct energy and thermal performance simulation, artificial and natural lighting analysis. To determine the modeling and the programming errors which can occur in the thermal dynamic simulation. I have validated and verified the accuracy of theses process based on a comparison between the thermal simulation and a reel field measurements data of dry-bulb temperature and humidity level that was obtained from an existing apartment in a collective residential building.

Generally, I have found that the results of the comparison show variations in the agreement between both data, in the different zones of the apartment. Some zones have an excellent agreement and others have some differences. The recorded dry-bulb temperature in the simulation was always higher than the measurement data. The opposite of the humidity level, the measurements were higher.

This was due to the missing inputs in the simulation, that were related to the occupant's behaviors of the other apartments in the building including; their numbers, the opening of the HVAC system, the windows/ doors closing and opening, time of occupancy…etc. The accurate inputs of all the parameters of the built environment impact the agreement degree between the measurements and the simulation results. Otherwise, since the agreement has been obtained in some zones in the apartment, that means the modeling method with Vi-suit add on Blender 3D was precise enough and it was used to fulfill the research main goal, Therefore, all the other parameters in the other apartments in the building were neglected and considered as fix variables in the research simulation methodology.

4.2 2nd theory

I have applied diagnosis of the existing building design in the Algerian hot and dry climate, in terms of building energy efficiency using Vi-suite add-on Blender 3D. First, the assessment was focused on the building heating and cooling consumption in the whole year, Meanwhile, the analytical methodology adopted for thermal comfort is based upon the Fanger’s model that includes Predicted Mean vote (PMV) and Predicted Percentage of Dissatisfied (PPD). Furthermore, the diagnosis is concerning also on visual comfort, assessing two main factors; the illuminance levels and the uniformity ratio. Finally, the analysis of the indoor air quality (IDQ) was focused on evaluating the amount of carbon dioxide (CO2) concentration in the indoor environment.

I have found that the energy consumption in the study context 89% was used on cooling, while 11 % was used on heating. Furthermore, the building energy diagnosis results generally were negative, and the residential building in the study context has not complied with the building energy design standards, there are many weaknesses in terms of building energy consumption, thermal comfort, visual comfort, and indoor air quality.

4.3 3rd theory

To optimize the conventional wall structure of the residential building, several materials have been selected based on the availability criteria, ecology, smart materials, and thermal/physical characteristics. As a result, these materials are including; various Brick types, Concrete, Stone, Sand, Phase change material (PCM), Earth materials, and thermal insulations. All these materials were analyzed compared with the base model to identify the best scenario in terms of cooling, heating demand, and thermal comfort.

After the analysis of each scenario. I have found that the best material that improves Energy demand was not the best on enhancing Thermal comfort. Besides, I have revealed that the conductivity was the main influential parameter on the energy demand; the material that has the lowest thermal conductivity provides the highest heating and cooling energy saving. However, the steady-state analysis of the Thermal Mass, Density, and specific heat proprieties of the materials could not provide a prediction for the material’s thermal performance. Thus, a dynamic simulation analysis is crucial to determine it.

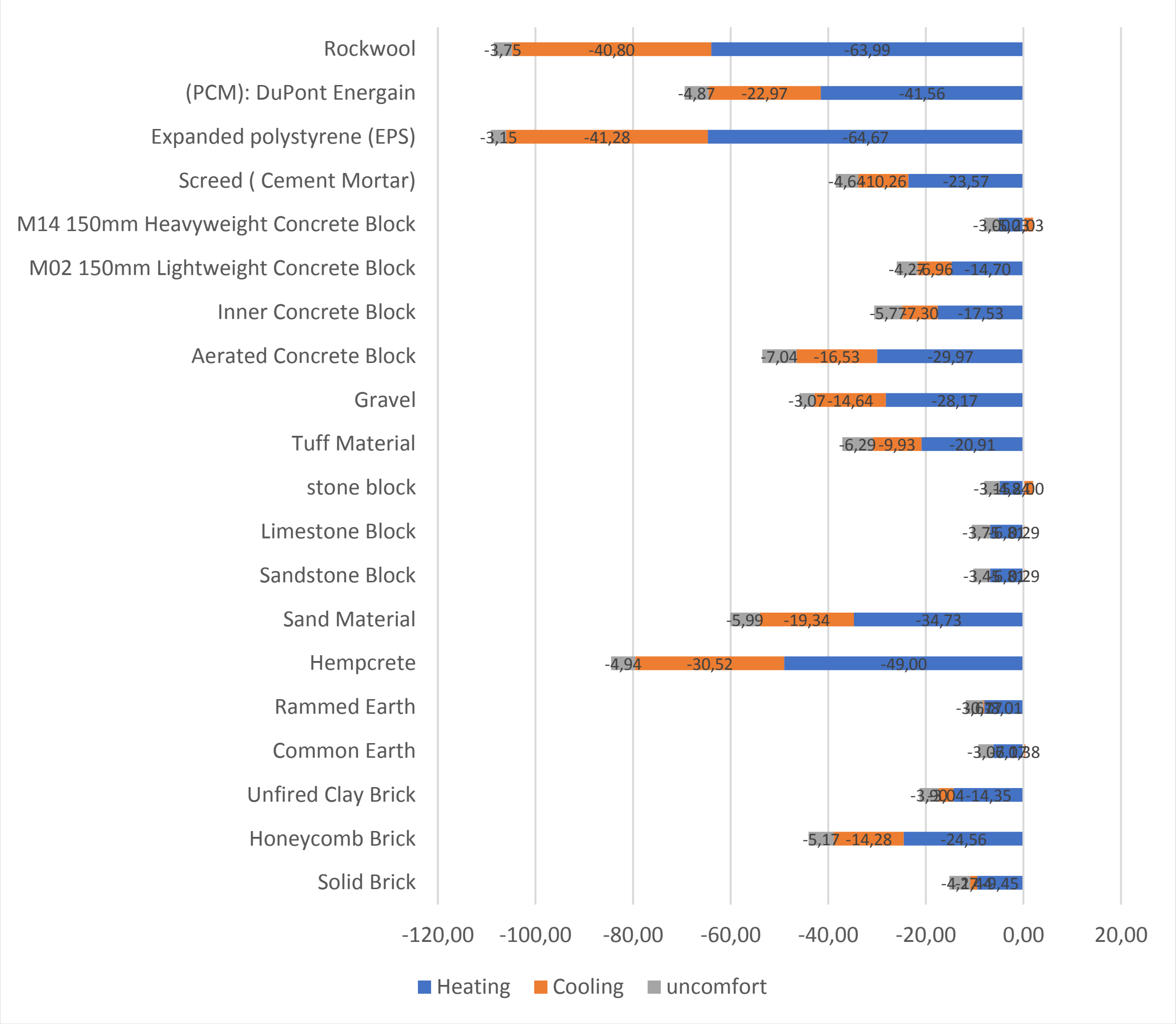

Figure 3: Interactive performance comparison between the different wall materials

4.4 4th theory

For the openings, The impact of two main parameters have been investigated; the WWR (from 20 % to 40%) and the glazing type (Simple pane, Double pane, and Triple pane). The impact of these parameters together with the orientation has been evaluated in an interactive method to improve the building energy demand, thermal comfort, daylight availability, and indoor air quality (IDQ). I have found that the orientation and the glazing type and WWR have a significant impact on the cooling and heating demand but in an inverse manner; the orientations that provide the best heating demand were the worst for the cooling demand. Additionally, the Simple pane glazing (SG) was compared with the two glazing type proposed in this study; double-pane glazing DG, and Triple pane glazing TG. I have revealed that applying DG or, TG decreases both cooling and heating demand compared with the SG, while the TG was the best alternative. Moreover, the glazing type efficiency is impacted by the orientations.

The comparison between the thermal comfort hours and the WWR in the orientations N, NE, NW indicate that since the WWR is higher the comfort hours are reduced, the contrary for the orientations SE, SW, W. In addition, the visual comfort and the indoor air quality was improved when the WWR was higher.

Furthermore, The performance analysis of the impact of the different alternatives on the different comfort aspects revealed that each nominated type of comfort; (daylight, thermal comfort, energy demand, and IDQ) lead to a different window configuration (glazing type, WWR). The WWR that provides better thermal comfort in each orientation was as follows: 20% in N, NE. NW orientations, 35% in E, SE, SW, W. In the S 25% was the best. And for the heating demand 20% in N, NE. NW orientations, 35% in E, 30% in SE, 40% in SW and W orientation. The 3 pane glazing was the best for all the orientations, while the S orientation the double-pane glazing was optimal with 40% WWR. The cooling demand increases as the WWR was higher, 20% was the best alternative for all the orientations with 3 pane glazing. Otherwise, for the daylight availability and indoor air quality, as soon as the WWR was higher these aspects offer better results. And for these aspects, 40% of WWR was the best for all the orientations.

The best design solutions in the study context were the clear 3 pane glazing for all orientations, and the WWR of 20% for the orientations NE, E, W, and 25% for the orientations S, SE, SW, NW. based on the classification of the desired indoor comfort as follows; IDQ, Thermal comfort, Cooling demand, Daylight availability, and Heating, determined.

Table 1: The optimum WWR and glazing type for each aspect

TG	WWR	Thermal comfort H							
		N	NE	E	SE	S	SW	W	NW
	20	1478	1275	1300	1634	2380	1630	1386	1299
	25	1449	1238	1319	1776	2496	1787	1408	1254
	30	1430	1206	1359	1943	2374	1899	1425	1220
	35	1418	1181	1370	1979	2167	1952	1439	1194
	40	1412	1154	1355	1919	1720	1900	1426	1168
	WWR	Heating demand kWh							
	20	96.10498	91.73307	33.19468	7.98396	3.608888	12.4981	42.87786	94.68289
	25	99.18169	93.70474	29.38821	6.69218	2.837367	9.675221	39.44223	96.84438

DG	30	102.7308	96.2115	27.56001	6.51206	2.420521	8.079092	37.42023	99.72205
	35	106.8683	99.22353	27.29763	6.679795	2.127906	7.440422	36.50545	103.1631
	40	111.5119	102.6858	27.89395	7.05038	1.864942	7.208603	36.35548	107.0413
TG	20	87.84358	84.51907	33.05082	8.717704	4.295058	13.13009	41.37844	87.03976
	25	88.79841	84.53064	28.56535	6.858816	3.276879	10.01058	37.28385	87.1566
	30	90.19872	85.17091	26.05561	6.516458	2.762613	8.214975	34.6674	88.04776
	35	92.06218	86.26426	25.18613	6.631712	2.345361	7.405618	33.16598	89.4283
	40	94.46393	87.74081	25.2686	6.944211	2.009512	7.086394	32.52231	91.26189
	WWR	Cooling demand kWh							
TG	20	955.5847	1103.614	1287.801	1385.429	1307.689	1385.522	1291.244	1104.414
	25	1002.701	1187.934	1433.499	1550.905	1451.242	1550.091	1436.87	1189.106
	30	1049.612	1272.079	1580.588	1716.918	1596.582	1715.151	1583.188	1273.546
	35	1096.486	1355.938	1728.582	1883.228	1744.708	1880.964	1729.692	1357.682
	40	1143.373	1439.527	1876.846	2050.891	1901.427	2047.853	1876.224	1441.775
		Daylight availability lux							
SG	20	3841	3892	3969	3934	3953	3899	3901	3865
	25	3947	3993	4075	4031	4004	4012	4011	3960
	30	4020	4057	4135	4083	4027	4057	4113	4032
	35	4027	4101	4177	4119	4038	4090	4155	4074
	40	4030	4125	4221	4136	4050	4102	4174	4097

4.5 5th theory

Based on the presented multi-objective optimization approach results, the alternative design solutions for the building were combined and compared with the existing residential building, I have found that the optimal combination of the façade design reduces 64 % of Heating demand, 3% of cooling demand, and improves 51 % of the indoor air quality. The thermal and visual comfort hours have been increased by 35%, 6 % respectively.

5. Scope and limitations

This study is focused on investigating the possibilities of optimizing the building facade design to improve building energy efficiency. The study is limited to the residential building in the Algerian hot and dry climate. Although, some of the findings may be generalized. Furthermore, the multiobjective optimization methodology can be applied in different contexts and different building types. Moreover, Façade load-bearing and acoustic comfort through the facade materials are not investigated in this study.