Paper 150: Bridging the gap between energy efficiency and comfort: a design strategy for Mediterranean areas

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Abstract

European Directive on the Energy Performance of Buildings requires practitioners to comply building design strategies with minimum energy performance requirements, while safeguarding thermal comfort. Some times and in some countries good energy efficient design strategies do not match with comfort requirements and vice versa. Good efficiency does not imply good comfort and bad comfort decreases efficiency.

This paper presents a methodology where energy efficiency and comfort are folded in the whole building design process, where both energy and design variables come up at the first steps of design. The methodology is based on regression equation models that predict both energy efficiency and comfort in winter and in summer as well. This way practitioner is guided into practice, bridging also the gap between codes and practice.

The regression equations models need independent and dependent variables. In this study these variables are collected from energy simulations of three buildings analyzed in Palermo, a city of south of Italy. The models offer valuable decision support systems for designers to optimize energy and comfort performance and a faster, easier and less expensive way than using building simulation tools.

Keywords: energy efficiency, comfort, regression equations

1. Introduction

Energy efficiency design solutions cannot be considered without reference to indoor environmental comfort [1]. Some time they are inversely related: the more efficiency the less comfort and vice versa [2]. To pursuit the energy efficient design that guarantees the appropriate balance between energy performance and IEQ both in winter and in summer, attention may be directed towards a methodology that combines results reliability and friendly energy prediction models. In this way time and money are saved due to the elimination of heavy computer-based simulation in the preliminary design phase.

Computer-based simulation assisting different aspects of architectural design have been developed for several decades [3] [4] [5]. But generally they are not used at the beginning of the design process. After the concept phase, the most architectural choices are already done and expertise, time and money are needed to change it. On the contrary, the task proposed in this paper for practitioners is to let them choose the right parameters at the first steps of design processes, supported by regression equations models, relating such choices to energy and comfort variables. This way practitioners save time and money by avoiding running heavy energy simulation at the first stage of design. To achieve this objective it is essential referring to integrated analysis techniques since the first steps of design. In fact, the choices architects make at this stage impact much more on operational costs during the building's lifecycle as well as on construction costs.

In this paper the integrated analysis techniques coincide with predictive models based on regression equations that consider three kinds of parameters: climate, design and technology . The first type of parameters concerns solar radiation, temperature, relative humidity and wind direction. The second type belongs to the architects choices: size and location of windows, physical properties of materials, surface treatment of envelope, relationship between glazed and opaque elements, mass, floor to ceiling height, and so on. The third type is linked to "sustainable" technologies such as buffer zones, double walls, shutters, etc.

Regression equations models have been chosen for this study because they are simple and practical tools useful to determine the impacts that architectural choices have on performance indicators, therefore optimizing the results. These models were used for predicting both thermal comfort and energy consumption. They are constructed from extensive simulation campaign carried out through DesignBuilder, a software tool using EnergyPlus as dynamic simulation engine [9]. Three recognizable architectures have been chosen for the energy analyses: Sarabhai House by Le Corbusier in India, the houses for the US Consulate in Luanda by L. Kahn and the house in Trentino (a north Italian region) by Matteo Thun. All of them are low raise residence and could have been built also in Mediterranean areas due to their peculiar architectural configurations and technology. Sarabhai House was chosen because of its technological characteristics that are linked to Mediterranean houses, such as vaulted ceilings and massive materials. The residential building for the US Consulate in Angola by Kahn matches with the Mediterranean design requirements thanks to the mass and the typology of opening. In the middle of these two excellent examples is the third case study: the House in Trentino by Matteo Thun whose Mediterranean design features are the shutters.

The three case studies have been simulated with DesignBuilder as they were in Palermo, in order to find interesting information for the objective of the research, which is providing a methodology to define “guidelines” that support practitioners in generating energy efficiency design in Palermo. Unfortunately, in Palermo there are not interesting examples of modern or contemporary architecture to look at. Therefore, Sarabhai House and the house for US Consulate in Angola are perfect examples of evolved traditional Mediterranean houses to look at. The house in Trentino has not characteristics related to mass, but it may be considered, due to the innovation it presents in technology.

After running the energy simulations of these case studies and their alternatives, a selection of independent and dependent variables has been used to build up regression equations. Design alternatives are obtained by varying one variable at a time, while keeping the others fixed. The dependent variables are energy efficiency and comfort. The independent variables concern design and energy parameters of the case studies and their alternatives.

2. Identification method

The system identification is a theory where models are built from observed data. The methodology of this study consists of three phases: specification, simulation and optimization. In the specification phase, all input data are needed to run the software. The simulation phase computes thermal and comfort performance in both summer and winter. The optimization phase consists of entering input and output obtained from the simulation phase and building up regression equations for predicting both energy efficiency and comfort in winter and in summer. Both winter and summer energy efficiency and comfort are considered as functions of building characteristics, energy performance components and energy control technology.

2.1 Energy computer base simulation

In order to build up regression equation models, both input and output have been collected and organized after running the energy computer simulations, by Design Builder [3], for the above three case studies. This software aims at the prediction of both energy consumption and thermal comfort in dynamic regime, in which time is an important variable. Buildings are divided in thermal zones and are characterized by the material and technology specifications described in [7].

Heating and cooling energy data have been calculated on an hourly basis over a period of one week each, using Palermo IWEC (International Weather for Energy Calculations) weather data. For each case study, the software has been used for predicting energy needs as well as comfort throughout day and night and over of seasons. Comfort has been assessed using PMV performance indicator in compliance with UNI EN ISO 7730 (UNI = Italian standardization body).

Simulations show how different technological solutions and building characteristics, in “as built” and in “alternative” configurations, affect both dependent variables: energy efficiency and comfort. The study investigates six architectural alternative configurations of both Sarabhai House and the US Consulate residence in Angola, and four alternative configurations of the House in Trentino. Alternatives in the as built versions are:

1. concrete beams and pillars with insulation according to law requirements in Palermo for US consulate residence and Sarabhai house (U-values: 0.54 W/m2K for walls and 0.42 W/m2K for roof), and window insulation (U-values: 3.6 W/m2K) according to law requirements for house in Trentino;
2. variation in height. Sarabhai House: from 5.50 to 4.60; US consulate residence: from 4.60 to 5.50; for the House in Trentino the variation concerns width;
3. elimination of the buffer zone for Sarabhai House; insertion of the double wall for US consulate residence and variation in shutter technology for House in Trentino;
4. variation of both floor to floor height and of technology in Sarabhai House and US consulate residence;
5. variation in orientation from north-east to est ovest for Sarabhai House and the House in Trentino and vice versa for US consulate residence;
6. as built with insulation for US consulate residence, Sarabhai House and the House in Trentino.

In the following tables the results of the simulations are accounted. Each simulation is splitted in four parts considering the building performance during a typical summer week without cooling system (sum), during a typical winter week without heating system (win) and during the same weeks, but with cooling (sum +

cool) and heating (win + heat) system, in order to evaluate the typical seasonal consumption.

Table 1: Energy consumption and Comfort values in winter and in summer, with and without cooling and heating for Sarabhai House by Le Corbusier and its alternatives.

		Orientation	Consumption	PMV
			kWh/m^2	-
Corbu 1	sum	NE	-	-0.29
	win	NE	-	-2.24
	sum + cool	NE	0.62	-0.44
	win + heat	NE	2.00	-1.71
Corbu 2	sum	NE	-	-0.78
	win	NE	-	-2.06
	sum + cool	NE	0.81	-0.97
	win + heat	NE	1.37	-1.61
Corbu 3	sum	NE	-	-0.28
	win	NE	-	-2.28
	sum + cool	NE	0.63	-0.58
	win + heat	NE	1.62	-1.72
Corbu 4	sum	NE	-	-0.09
	win	NE	-	-2.63
	sum + cool	NE	0.77	-0.36
	win + heat	NE	5.04	-2.00
Corbu 5	sum	NE	-	-0.11
	win	NE	-	-2.61
	sum + cool	NE	0.64	-0.40
	win + heat	NE	4.14	-1.97
Corbu 6	sum	EO	-	-0.36
	win	EO	-	-2.27
	sum + cool	EO	0.55	-0.48
	win + heat	EO	1.98	-1.70
Corbu 7	sum	NE	-	-0.11
	win	NE	-	-1.67
	sum + cool	NE	0.75	-0.29
	win + heat	NE	0.80	-1.44

Table 2: Energy consumption and Comfort values in winter and in summer, with and without cooling and heating for US Consulate Houses in Luanda by L. Kahn, Angola and its alternatives.

		Orientation	Consumption	PMV
			kWh/m^2	-
Kahn 1	sum	EO	-	0.82
	win	EO	-	-2.72
	sum + cool	EO	0.44	0.27
	win + heat	EO	5.38	-1.82
Kahn 2	sum	EO	-	0.70
	win	EO	-	-2.71
	sum + cool	EO	0.35	0.12
	win + heat	EO	4.78	-1.74
Kahn 3	sum	EO	-	0.90
	win	EO	-	-2.71
	sum + cool	EO	0.54	0.32
	win + heat	EO	5.82	-1.82
Kahn 4	sum	EO	-	0.82
	win	EO	-	-2.72
	sum + cool	EO	0.44	0.27
	win + heat	EO	5.39	-1.81
Kahn 5	sum	EO	-	0.90
	win	EO	-	-2.72
	sum + cool	EO	0.53	0.32
	win + heat	EO	5.82	-1.82
Kahn 6	sum	NE	-	0.86
	win	NE	-	-2.71
	sum + cool	NE	0.46	0.30
	win + heat	NE	5.32	-1.81
Kahn 7	sum	EO	-	0.73
	win	EO	-	-2.55
	sum + cool	EO	0.33	0.17
	win + heat	EO	3.98	-1.70

Table 3: Energy consumption and Comfort values in winter and in summer, with and without cooling and heating for House in Trentino by Matteo Thun, Angola and its alternatives.

		Orientation	Consumption	PMV
			kWh	-
Thun 1	sum	NE	-	-0.04
	win	NE	-	-2.05
	sum + cool	NE	0.16	-0.16
	win + heat	NE	2.20	-1.46
Thun 2	sum	NE	-	-0.09
	win	NE	-	-2.15
	sum + cool	NE	0.14	-0.20
	win + heat	NE	2.19	-1.52
Thun 3	sum	NE	-	-0.19
	win	NE	-	-2.24
	sum + cool	NE	0.12	-0.28
	win + heat	NE	2.51	-1.53
Thun 4	sum	EO	-	0.01
	win	EO	-	-2.21
	sum + cool	EO	4.95	-0.12
	win + heat	EO	9.77	-1.54
Thun 5	sum	NE	-	0.35
	win	NE	-	-1.67
	sum + cool	NE	0.29	0.13
	win + heat	NE	1.16	-1.29

2.2 Method to determine regression equation

Simulation input and output have been used to determine regression equations. The regression is a method that models the relationship between a dependent variable (in this case energy efficiency and comfort in winter and in summer) and independent variables (building characteristics, energy performance components and energy control technology).

Building characteristics consist in area, volume and floor-to-floor height. Component energy characteristics have been synthesized as energy gain and losses of walls, roofs and windows (due to the difference among the buildings it is very difficult to fix an actual independent variable and the use of such intermediate variable seems solve the question). Energy control technologies include buffer zone (Le Corbusier), double walls (Louis Kahn) and shutter devices (Matteo Thun). Environmental conditions including latitude, altitude, ambient temperature, degree-days and sun hours, have not been considered due to the fact the location investigated, Palermo, is constant.

Between simulation and optimization there is an intermediate phase, which is the Pearson's correlation analysis [3]. The correlation indicates the direction and the strength of a linear relationship between a dependent and an independent variable. The relation between the two variables is indicated with (+) when they are straight proportional and with (-) when they are inversely proportional.

Here are summarized the most meaningful correlations between the two category of independent variables and energy consumption :

A - for energy variables:

- *in summer:*

1. wall thermal transmittance (-)
2. window thermal transmittance (+)
3. roof thermal transmittance (+)

- *in winter:*

4. wall thermal transmittance (+)
5. window thermal transmittance (+)
6. roof thermal transmittance (+)
7. gain - losses walls (-)
8. gain - losses roof(-)

B - for building characteristics:

- *in summer:*

1. floor to ceiling height (+)
2. area (+)
3. volume (+)

- *in winter:*

4. control energy technology (-)
5. volume (+)

The most meaningful correlations between independent variables and comfort analyzed without temperature control (nor heating neither cooling systems) are:

A - for energy variables:

- *in summer:*

1. wall thermal transmittance (-)
2. window thermal transmittance (+)
3. gain/losses through window (-)
4. gain/losses due to ventilation (-)

- *in winter:*

5. wall thermal transmittance (+)
6. roof thermal transmittance (+)
7. gain/losses through roof (-)

B - for building characteristics:

- *in summer:*

1. floor to ceiling height (+)

- *in winter:*

2. control energy technology (-)

The most meaningful correlations between independent variables and comfort analyzed with temperature control, heating and cooling systems are:

A - for energy variables:

- *in summer:*

1. wall thermal transmittance (-)
2. gain/losses through walls(+)
3. gain/losses through roof (-)
4. gain/losses due to ventilation (-)

- *in winter:*

5. roof thermal transmittance (-)
6. window thermal transmittance (-)
7. gain/losses through roof (+)

B - for building characteristics:

- *in summer:*

3. volume (-)

- *in winter:*

4. floor to ceiling height (-)
5. area (-)

From the first results it can be said that, besides thermal transmittance, energy control technology, volume and height have a significant impact on energy consumption. The presence of technology is inversely proportional to energy consumption: it lowers cooling and heating needs. Reduction in winter consumption is twice as much in summer. Height has a great effect in winter: the higher a building the more the consumption. Instead volume impacts more in summer: the wider the volume the more the energy consumption. In addition, in winter thermal transmittance reduction implies a drop in consumption, whereas in summer a rise. Concerning the comfort in winter in an unheated building, gains and losses are very important, while technology impacts negatively. In summer is the height the most important variable besides thermal transmittance. Concerning the comfort with heating system in winter, technology and height are important and directly proportional. Whereas in summer technology and comfort are directly proportional, whereas volume and comfort indirectly.

In order to simplify the communication of this paper, the name of variables are synthesized according to the following table.

Table 4: The variables used for the analysis

Variable	Name	Unit
Energy consumption in winter	Winter CONSUMPTION	kW/m^2
Energy consumption in summer	Summer CONSUMPTION	kW/m^2
Comfort in winter (without heating system)	Winter PMV NAT	---
Comfort in summer (without cooling system)	Summer PMV NAT	---
Comfort in winter (with heating system)	PMV Heat	---
Comfort in winter (with cooling system)	PMV Cool	---
Building Area	Area	m^2
Building Volume	Volume	m^3
Floor to ceiling height	FLOOR HEIGHT	m
Wall Thermal transmittance	U WALL	W/m^{2}K
Glass Thermal transmittance	U GLASS	W/m^{2}K
Roof Thermal transmittance	U ROOF	W/m^{2}K
Energy control technology (buffer or shutter or double wall)	Env Tech	dummy (0 or 1)
Gain/losses through windows (without heating/cooling system)	wind g/l nat win/sum	kWh
Gain/losses through windows (with heating/cooling system)	wind g/l HEAT/COOL	kWh
Gain/losses through walls (without heating/cooling system)	wall g/l nat win/sum	kWh
Gain/losses through walls (with heating/cooling system)	wall g/l HEAT/COOL	kWh
Gain/losses through roof (without heating/cooling system)	roof g/l nat win/sum	kWh
Gain/losses throughout walls (with heating/cooling system)	roof g/l HEAT/COOL	kWh
Gain/losses due to ventilation (without heating/cooling system)	vent g/l nat win/sum	kWh
Gain/losses due to ventilation (with heating/cooling system)	vent g/l HEAT/COOL	kWh

After identifying the correlations between dependent and independent variables, a multicollinearity analysis has been carried out. This analysis reduces the number of variables that convey essentially the same information. Below are the variables that do not present multicollinearity problem. These variables, coming from the auxiliary regression analysis, will be used to build up the regression models:

- to winter energy consumption: *U wall, U roof, wind g/l, roof g/l, Floor Height, Env Tech.*

- to summer energy consumption: *U wall, U roof, Env Tech, vent g/l, Volume.*

- to winter comfort with energy means: *U wall, U roof, wind g/l, vent g/l, Floor Height, Env Tech.*

- to winter comfort without energy means: *U wall, U roof, wind g/l, wall g/l, roof g/l, vent g/l, Env Tech.*

- to summer comfort with energy means: *U wall, U roof, wind g/l, walls g/l, Env Tech, Volume*

- to summer comfort without energy means: *U wall, U roof, wind g/l, wall g/l, roof g/l, Floor Height.*

All these variables shall be related into parametric equations. For this purpose a statistical software was used, the Minitab [8], where all independent were related to each dependent variable. This way six-regression models were set up and reported in section 2.3.

2.3 First results

The stated above regression models are reported in the following. For the variables specifications see table 4. The models could be used to carried out buildings performance sensitivity analysis depending on the analyzed independent variables.

Winter CONSUMPTION = - 3.89 + 1.93 U WALL - 0.066 U ROOF - 0.00436 wind g/l HEAT - 0.00419 roo g/l HEAT + 0.976 FLOOR HEIGHT - 1.05 ENV. TECH.

All predictors are enough significant except the U Roof. which presents a too high value of p. The R-Sq = 71.4%. That means that data are enough reliable.

Summer CONSUMPTION = 0.239 - 0.122 U WALL + 0.0558 U ROOF - 0.000050 vent g/l COOL - 0.0658 ENV. TECH. + 0.000079 Volume

All predictors are more significant than the ones in the previous relation due to the lower p value. The R-Sq = 91.3%. That proves the reliability of the results.

Winter PMV NAT = - 2.54 + 1.86 U WALL - 0.195 U ROOF + 0.00057 wind g/l nat win + 0.0136 wall g/l nat win - 0.0254 roof g/l nat win - 0.00178 vent g/l nat win - 1.51 ENV. TECH.

Also in this case the reliability of the relation is high: R-Sq = 84.8%.

Summer PMV NAT = - 1.00 + 0.755 U WALL - 0.613 U ROOF + 0.293 U GLASS - 0.00039 wind g/l nat sum + 0.00050 wall g/l nat sum + 0.000902 roof g/l nat sum + 0.056 FLOOR HEIGHT

R-Sq = 77.6%.

PMV Cool = - 0.222 + 0.209 U WALL - 0.096 U ROOF - 0.00294 wind g/l COOL + 0.000928 wall g/l COOL + 0.106 ENV. TECH. - 0.000079 Volume

R-Sq = 83.8%

PMV Heat = - 1.73 + 0.184 U WALL - 0.224 U ROOF - 0.000855 windows g/l HEAT + 0.000120 vent g/l HEAT + 0.0126 FLOR HEIGHT + 0.119 ENV. TECH.

R-Sq = 90.4%

3. Conclusion

This paper has described the development of regression equations based on an identification process, using linear regression elaborating data obtained from simulations performed with a building dynamic simulation tool.

Regression equation models have been used for the purpose of thermal comfort and energy efficiency prediction. These models are more rapid and easier ways than using detailed building simulation tools, which are still complicated, time-consuming and expensive for many building practitioners, in particular at the very first stage of the design process when it is so difficult be able to invest time and money in a project.

In fact, these models would be used at an early design stage, allowing the designer to model the building, in order to optimize thermal performance and comfort. The methodology described for Palermo, can be used on any building and region to support the design choices. The regression curves, which are six in this study, demarcate the optimization areas. This means that the solutions chosen for any category of design, such as windows, walls, etc., which would mark points on several 2-D or 3-D diagram matching two or three variables at a time, have to be contained in the optimization area. For example, decisions may concern the dimension of windows, the thickness of walls, and so on according to the choice of practitioners.

The target is to find the most appropriate energy and architectural variables and their relationship. It can be considered the basis to set up guidelines for practitioners to design energy efficient buildings. In brief, the model may be, on one hand, a tool to be used by architects and engineers to predict energy efficiency and comfort in the first steps of design. On the other hand, government and institutional bodies that control and regulate construction on a regional level may use it to target new regulations. Clearly, the research cannot be considered exhaustive due to the complexity of the energy topic. There are several variables and case studies to be still investigated, in order to consider the model completely reliable and general.

Further researches will be focused on the use of the developed predictive equations including window location and orientation, space configuration and other architectural variables in the predictive model formulae.

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