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## APPROACH TO PROCEDURES OF CALCULATION AND LOGGING OF MODELS ON SCALE FOR THE THERMAL SIMULATION OF CONSTRUCTIONS

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### ABSTRACT:

With this investigation the visual and aesthetic functions of the models on scale are surpassed to enter to the thermal simulation, from where knowledge is obtained on thermal properties of construction materials, phenomena of heat transference in constructions, form factor and scale; finally to establish the methods of calculation and thermal logging like design tool towards an architecture of high environmental quality. From form analysis, materials and thermo physics properties of materials and taken real architectonic spaces like pattern, are designed and construct scale models that represent the thermal behavior of the real space in free evolution. The study of the phenomenon of heat transference by conduction in the constructions, constitutes the theoretical - scientist basis of this investigation, also the mathematical application of the theory of the similarity and models like the adimensionals groups, are important in the design procedure and calculation of the models. Conference Topic: 3.2 Modelling and Simulation

## INTRODUCTION

The architecture like discipline has to guarantee the comfort and the quality in the spaces that project, assuming with responsibility the relation of the building with the surroundings and the environment, in addition to the cultural and physical determinants of the places. This commitment assumes in many cases with simulation strategies of the spaces and the buildings with design tools as the sketch (drawing and perspective), the scale models and demonstrations by software, these last ones widely spread by the advance of computer science.

These design tools have been the approach to physical characteristics such as the form, textures and colors; structural like constructive and material systems; and aesthetic like languages and meaning. The simulation by software has enriched the exploration in the architecture, now we can count on programs that execute energy routines, solar incidence and thermal simulation that help the projects to obtain an excellent quality; due to the prediction of many factors that influence in the life and the function of the building, as the sunlighting, artificial illumination, even until the acoustic behavior; all these with acceptable levels of reliability, but some times are expensive by being specialized or developed in other latitudes.

The simulation models as scale models allow precise approaches to real conditions like the climate, the physical conditions of the places, the materials and the measurement of data in real time, subject little explored, but that hopes to extend the visual functions and physical of the scale models to turn them into tools that contribute conclusions for the buildings comfort like the temperature and its free evolution in a project.

## THEORETICAL BASIS

### Tests in Models[1]

The tests in models constitute in a valuable tool for the architects designers, the scale models are light, of easy construction, relatively economic and in addition they offer the possibility of becoming laboratories of materials and projects (See Image 1).



Image 1: Construction of a simulation model with expanded polystyrene

The physical models can be complemented with the computer science models, due to first display the possibility of working in means and real time, giving a faithful answer to the natural phenomena like the climate and its incidence in the constructions, object of our study.

This project looks for to define processes that allow the construction of models on scale to evaluate the phenomenon of heat transmission by thermal conductivity in materials and proportional air volumes or on scale of a taken real model like reference.

### Theory of the Similarity [2]

The mechanics of the similarity is based on the possibility of transmitting the conclusions of observations of physical phenomena that affect a model pattern, to a similar system done on another scale.

This similarity does not only talk about to a relation between the geometric measures between model and prototype, but that is applied with all majority to all the physical magnitudes that take part in the phenomenon and which they can be comparable like the time, the temperature, forces, acceleration, etc.

Geometric similarity between two systems exists when the reason between its significant dimensions is the same one for both systems. For example, if the reason of the dimensions  $a/b$  for the model, has the same magnitude  $a/b$  of the prototype. In the case of having several more complicated dimensions or geometric forms, the geometric similarity will require that all the geometric reasons are equal between the model and the prototype.

In order to understand the theory of the models it is important to remember that the formulated natural laws mathematically are only valid in a field of smaller application, but do not assure anything with respect to his own application. By this to be able to transmit conclusions of a prototype to a model it must be guaranteed that the hypotheses on that are fulfilled sufficient approach the applied laws are based; that is to say, the conditions of similarity must be contained in fundamental equations.

Leaving the validity of the conditions of similarity deduced of the corresponding equations differentials, phenomena of great importance exist actually in which he is very complicated to define these equations, these are constituted in phenomena analytically impossible to solve, which can be boarded with tests in models like procedure to understand their processes.

It is possible to define similarity conditions for the tests between the prototype and the model without exactly knowing the form the fundamental equations, for this it is necessary to know the magnitudes physical that affect the phenomenon that hopes to analyze, this procedure is obtained from the dimensional analysis, method that goes beyond the tests in models due to it is constituted in a work tool that allows to make analysis comparative and to establish hypothesis of work for the experimental investigation in the thermal simulation of constructions.

### Dimensional homogeneity

This law is important when situations appear and the variables that take part in a physical phenomenon are known, whereas the relation between the variables is unknown. By means of the dimensional analysis, the phenomenon can appear like a relation between a assembly of adimensionals groups of the variables, being the number of groups smaller than the one of the variables. The dimensional analysis is another way to maintain the consistency dimensional. It is to group the variables of a situation given in parameters devoid of dimension, less numerous than the original variables.

The direct advantage of this method is in which require a smaller experimentation to establish the relation between the variables in a given rank. If the variables are combined to form a smaller number of parameters without dimension, the task of reduction of the experimental data is diminished.

So that the dimensional analysis can be applied of reliable form is necessary to have much taken care of with the chosen physical magnitudes, these must be most important within the phenomenon that hopes to simulate, as much in the prototype as in the model, specially in the incidence of the scale.

With the dimensional analysis the necessary conditions for the definition of the similarity laws are not obtained, but it generates rules to obtain possible conditions of similarity that of another form would be found by chance. A form to control the correct selection of the used physical magnitudes is to make comparative analyses of simulation in several scales of models.

#### Dimensional analysis

Must select the physical magnitudes considered like decisive in the description of the phenomenon and obtaining combinations that are adimensionals. The content of the matrix conforms the exponents of dimension in the fundamental units of the selected physical magnitudes. This matrix is a tool used in the theorem of Buckingham: "The number of contained adimensionals products in a complete system is equal to the number of the physical magnitudes that take part in the phenomenon, diminished in the order of the matrix determined by the units it bases necessary" (See figure 1).

<b>M</b>	<b>α</b>	<b>β</b>	<b>γ</b>	<b>δ</b>
1	0	3	0	0
L	-1	-2	1	2
t	2	1	1	1

1	0	3	0
-1	-2	1	2
2	1	1	1

Figure 1: Matrix used in the theorem of Buckingham

## METHODOLOGY

### Project Definition

For the tests of thermal simulation in models the investigation was divided in phases of analyses corresponding to the individual study of the phenomena of heat transference that affect the temperature of the constructions, the first phase corresponds to the phenomenon of thermal conduction, for this study calculated the adimensionals groups, were constructed the models and they were controlled, to have comparative analyses that validate the used method and allow the evaluation of the phenomenon. The conduction is the phenomenon of greater effect on the inner heating of space, pronounces by walls and cover, this directly related to the properties and thickness of the materials. The phenomena of radiation and convection are object of study at the present time, of which not yet conclusions are had.

### Calculation of Adimensional Group for Conduction.

The phenomenon of the heat Conduction is given by the equation:

$$Q = K S \Delta T^\circ / L \quad [3]$$

Where:

Q = the heat flow.

K = the thermal Conductivity of the material.

S = The Area.

$\Delta T^\circ$  =, temperature difference

L = Thickness of the material.

It must be the relation between Q and the other variables by means of the dimensional analysis. First the amount of  $\pi$  must be decided in careful form independent. Therefore, the dimensional matrix is used using system M, L, t,  $T^\circ$  (See Table 1)

Table 1: Dimensional matrix based on the Buckingham's theorem

	K	S	T°	L	Q
M	1	0	0	0	1
L	1	2	0	1	2
T	-1	0	1	0	0
T°	-3	0	0	1	-3

Where:

$$Q = ML^2/T^3$$

$$K = ML/tT^3$$

$$S = L^2$$

$$\Delta T^\circ = t$$

$$L = L.$$

If  $Q = f(K, S, T, L)$  Then:

$$Q = k_1 [(K)^a (S)^b (T)^c (L)^d] \quad \text{Equation 1}$$

$$[ML^2/T^3] = [ML/tT^3]^a [L^2]^b [T]^c [L]^d.$$

From the law of dimensional homogeneity, when equaling the exponents of the basic dimensions, can say that:

$$\text{For M} \quad = \quad 1 = a$$

$$\text{For L} \quad = \quad 2 = a + 2b + d$$

$$\text{For t} \quad = \quad 0 = -a + c$$

$$\text{For T} \quad = \quad -3 = -3a$$

Therefore, selecting a and b to clear them based on c and d (this means that K and S must appear in one of the adimensionals groups), is required that:

$$1 = a \quad a = 1$$

$$2 = a + 2b + d \quad d = 1 - 2b$$

$$0 = -a + c \quad c = a$$

$$-3 = -3a \quad a = 1$$

Afterwards, when returning Equation 1, can conclude that:

$$Q = k_1 [(K)^1 (S)^b (T)^1 (L)^{1-2b}]$$

Grouping the terms with such explaining,

$$Q = k_1 [KTL] [S/L^2]^b$$

$$Q / [KTL] = k_1 [S/L^2]^b$$

Returning to the functional form:

$$Q / [KTL] = f [S/L^2]$$

This way obtains two adimensionals groups. If the adimensionals groups of the function are multiplied (in the case of being several) and the result is reversed, it is obtained:

$$Q / [KTL] = [L^2/S]$$

Values of K for materials of Scale models

To construct the models in light materials was necessary to determine the values of K in laboratory by means of "Hot Board Method". The analyzed materials were expanded Polystyrene, industrial cardboard and Straw-cardboard, the method of the hot board served in addition to verify the values defined by ASRHAE, for the materials of the model and the prototype.

The values determined in laboratory were:

$$\text{Expanded polystyrene } K = 0.37$$

$$\text{Industrial Cardboard } K = 0.83$$

$$\text{Straw-cardboard } K = 0.57$$

### Design of Models.

The models calculated in relation to an existing space, of which their dimensions were defined and the thermo physics characteristics of their constituent materials, the prototype contributes to the test the relation between contained air volume and surfaces, from as it is establishes the geometric similarity with these on different scales (See Table 2). For this study a prototype 1:5 was defined, soon were constructed models on scale 1:10, 1:15 and 1:20 applying the adimensional number for defined conductivity previously.

Table 2: Dimensions to establish the geometric homogeneity of the models with the existing space, relation between contained volume and surface of Cover.

		Existing Space	Model Scale 1:5	Model Scale 1:10	Model Scale 1:15	Model Scale 1:20
Air Contained	Wide	2.30m	0.46m	0.23m	0.153m	0.115m
	Deep	3.30m	0.66m	0.33m	0.21m	0.165m
	Height	2.60m	0.525m	0.2625m	0.175m	0.131m
	Total m3	19,92	0,1594	0,0199	0,00562	0,00248
Covered Surface	Wide	2.30m	0.46m	0.23m	0.153m	0.115m
	Longitud	3.34m	0.668m	0.334m	0.22m	0,167
	Total m2	7,682	0,307	0,0768	0,0336	0,0192
	Thickness	0.15m	0.03m	0.015m	0.010m	0,0075

The ventilation of the model was handled in proportion with the entrances and exits of air that displays the prototype, equaling renovation conditions of the air to avoid locked up volumes (See Table 3).

Table 3: Relation between contained air volume versus ventilation surfaces.

	Scale 1:5	Scale 1:10	Scale 1:15	Scale 1:20
<b>Air Volume</b>	<b>0,1594m3</b>	<b>0,0199m3</b>	<b>0,00588m3</b>	<b>0,0025m3</b>
<b>Area Vain</b>	<b>0,099m2</b>	<b>0,025m2</b>	<b>0,015m2</b>	<b>0,0062m2</b>

The models were constructed with expanded Polystyrene, the values of K for the materials of the existing space were taken from ASRHAE [4], for the scale model took the data obtained in laboratory (See Table 4).

Table 4: Values of coefficient of conductivity (k) of the materials of the real space and the scale models, the thickness are defined in millimeters.

Material	Thickness (mm) (e)	Conductivity W/(m*K) (k)
<b>Brik</b>	<b>150</b>	<b>0,563</b>
<b>Brik of Roofing</b>	<b>150</b>	<b>0,576</b>
	<b>30</b>	<b>0,037</b>
<b>Expanded Polyetyrene</b>	<b>15</b>	<b>0,037</b>
	<b>10</b>	<b>0,037</b>
	<b>7,5</b>	<b>0,037</b>

Applying the Fourier's law for thermal conduction and the adimensional number  $Q/KTL$ , the values for the heat flow in each one of the models settle down (See Table 5).

Table 5: Values of the variables grouped in the adimensional number for each one of the scale models and prototype.

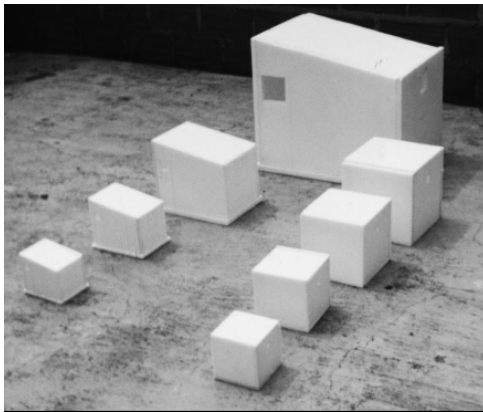
Variables	Existing Space	Model Scale 1:5	Model Scale 1:10	Model Scale 1:15	Model Scale 1:20
K in W/mK	0,563	0,37	0,37	0,37	0,37
A in m <sup>2</sup>	1	0,04	0,01	0,0044	0,0025
T in °C	1	1	1	1	1
L in m	0,15	0,03	0,015	0,01	0,0075
Q	3,753	0,0493	0,0246	0,016	0,0123

Calculations of dimensional homogeneity:

Starting off of the variables of the adimensional group, we equaled the data for the prototype and the model:

$$K_p T_p L_p = K_m T_m L_m \quad \text{Equation 2}$$

Of table 5 the relations of proportion between the variables settle down like this:



$$L_p = 5L_m, K_p = 15.21K_m, Q_p = 76.08Q_m$$

Of equation 2  $T_p$  is sprightly and the values are replaced:

$$T_p = \frac{Q_p K_m L_m T_m}{Q_m K_p L_p} \quad T_p = \frac{(76.08Q_m) K_m L_m T_m}{Q_m (15.21K_m) (5L_m)}$$

$$T_p = \frac{76.08 T_m}{76.05} = 1T_m \quad T_p = T_m$$

In the same way it is come with the scale models in scale 1:10, 1:15 and 1:20; conserving the dimensional homogeneity. After the dimensional analyses, the models are arranged to the thermal logging (See Image 2).

Image 2: Scale models constructed from the dimensional and thermal analyses, in relation to an existing space, the models are defined by scale and contained air volumes.

## THERMAL LOGGING

### Evaluation of Models on Free Evolution

The thermal logging is managed to evaluate the behavior of the models on scale in free evolution, these tests complement the described mathematical method, with this process settle down for them model conditions of similarity with the prototype as far as its relation with the surroundings, specifically its direction with respect to the solar incidence, the tests are made in exteriors and simultaneously where the climatic phenomena similarly affect the elements of this laboratory.

The data of the air temperature and the surfaces, contribute to the global thermal behavior of the inner space, which represents the purpose of this investigation.

### Equipment and Methodology

The equipment used in the thermal logging is essentially sensorial of air temperature and surfaces, programmable by computer: 10 sensors HOB0 [5] of air temperature of, 2 multi-channel sensors HOB0 (x4), 12 Thermo-domes for surfaces temperature, infrared Sensor for surfaces, Software BoxCar Pro 4,0 [6], Cable for Programming, and Excel.

The taking of data is made every 3 minutes, there are free evolution tests from hours, to complete days due to the autonomy of the equipment, the sensors must be preserved of strange factors and airflows, its installation must be similar in all the models

## ANALYSIS AND RESULTS

The data obtained in the thermal logging allow the graphical representation of the evolution of temperature in each one of the models, contrasted with the outer temperature, the process of the information is made by Excel. The tables of data become to curves of evolution of Temperatures (°C) per time ( See Figure 2).

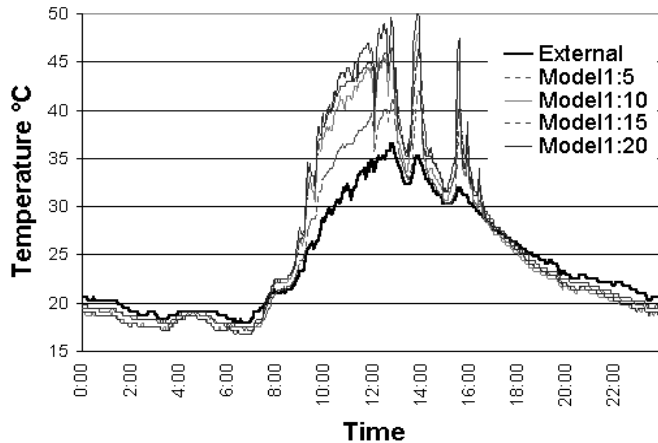


Figure 2: Free evolution curves of temperatures of 24 hours to the interior of each model superposed with outer temperature average.

This representation allows to make comparative analyses between the models and the prototype having like reference the outer temperature, as it can notice in figure 1, the scale models displays the same form in the thermal oscillation without phase angles in the periods of gains and lost, they are even sensible to the own changes in the climatic phenomena like cloudiness or diminution of the solar radiation, each model moves away of the outside in proportion to its size since they present a smaller air volume to warm up, this difference can mathematically be analyzed from the exposed panels of caloric flow in numeral 3 of this report.

With the results of the thermal logging and the confrontation with the mathematical procedure the models in panels are analyzed summary that sustain the comparative analysis (See Table 6).

Table 6: Panel summarizes for comparative analysis between the scale models and the outer temperature.

	Initial Temp.	Temp. Average	Maxim Temp.	Thermal Jump	Time of Jump	Speed of Heating	Dif. Outer Avr.
<b>External</b>	21,33	26,98	35,08	13,75	6h54'	1,99C/h	0
<b>MODELS</b>							
Scale1:20	21,7	31,55	45,3	23,6	7h33'	3,12C/h	4,57
Scale1:15	21,33	31,47	44,89	23,56	7h18'	3,23C/h	4,49
Scale1:10	21,33	31,3	44,89	23,56	7h15'	3,25C/h	4,32
Scale1:5	21,71	29,63	41,52	19,81	7h09'	2,77C/h	2,65

Considering which the global behavior of the models imagines, the margin of error for each scale model can be considered from the intervention of the phenomena of Convection and Radiation, due to this approach calculated for the Conduction, the adimensionals groups for the other phenomena of heat transference can previously be calculated from their fundamental equations and following the procedure described previously.

## CONCLUSIONS

The models of thermal simulation in the architectonic design can get become valuable tools for architects and constructors, due to they allow to know the properties and behavior the inner spaces in a previous stage the construction, the interaction of the project with the immediate surroundings and its possible thermal behavior before the solar incidence and the climatic phenomena.

This way of simulation are relatively economic and the models are of easy construction, the range of materials can be chosen by the architect knowing previously their thermal properties.

Once calibrated the models of thermal simulation the analysis process is reversed, well-known the properties and the behavior of the model is analyzed analogous with the project in its phase of design. The method made up of mathematical analysis and the thermal logging are complemented to give rise to the homogeneity law that been worth east type of tests.

The simulation in models on scale allows the approach to the average real physicist where the project will be implanted, allowing to evaluate the conditions of surroundings of direct way and not assuming data like computer science means. The possibility of validating the tests in different scales and materials enriches the options of the method of analysis and proposed design.

The study of the phenomena of heat transference by Convection and Conduction inside the spaces is being evaluated at the moment to complement this methodology.

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