EVALUATION AND PARAMETRIC OPTIMIZATION OF THE HEATING LOAD AND COMFORT CONDITIONS IN A SCHOOL BUILDING

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THE LFC RESEARCH PROJECT

THE LBP RESEARCH PROJECT - Introduction

A MAJOR PROGRAM OF REFURBISHMENT OF SCHOOL BUILDINGS IS RUNNING IN PORTUGAL

INCREASE THE ENERGY EFFICIENCY OF THE BUILDINGS

IMPROVE THE INDOOR LEARNING ENVIRONMENT IN TERMS OF THERMAL COMFORT AND INDOOR AIR QUALITY

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THE LBP RESEARCH PROJECT - Objectives

LABORATORY OF BUILDING PHYSICS

Faculty of Engineering of University of Porto

- Assess the indoor environmental quality

Measurement of:

- *Air Temperature* [ºC]
- *Relative Humidity* [%]
- *Carbon Dioxide Concentration* [ppm]

- Optimization of constructive solutions to be used in the rehabilitation of school buildings

Objectives:

- *Thermal Comfort*
- *Indoor Air Quality*
- *Economic Sustainability*

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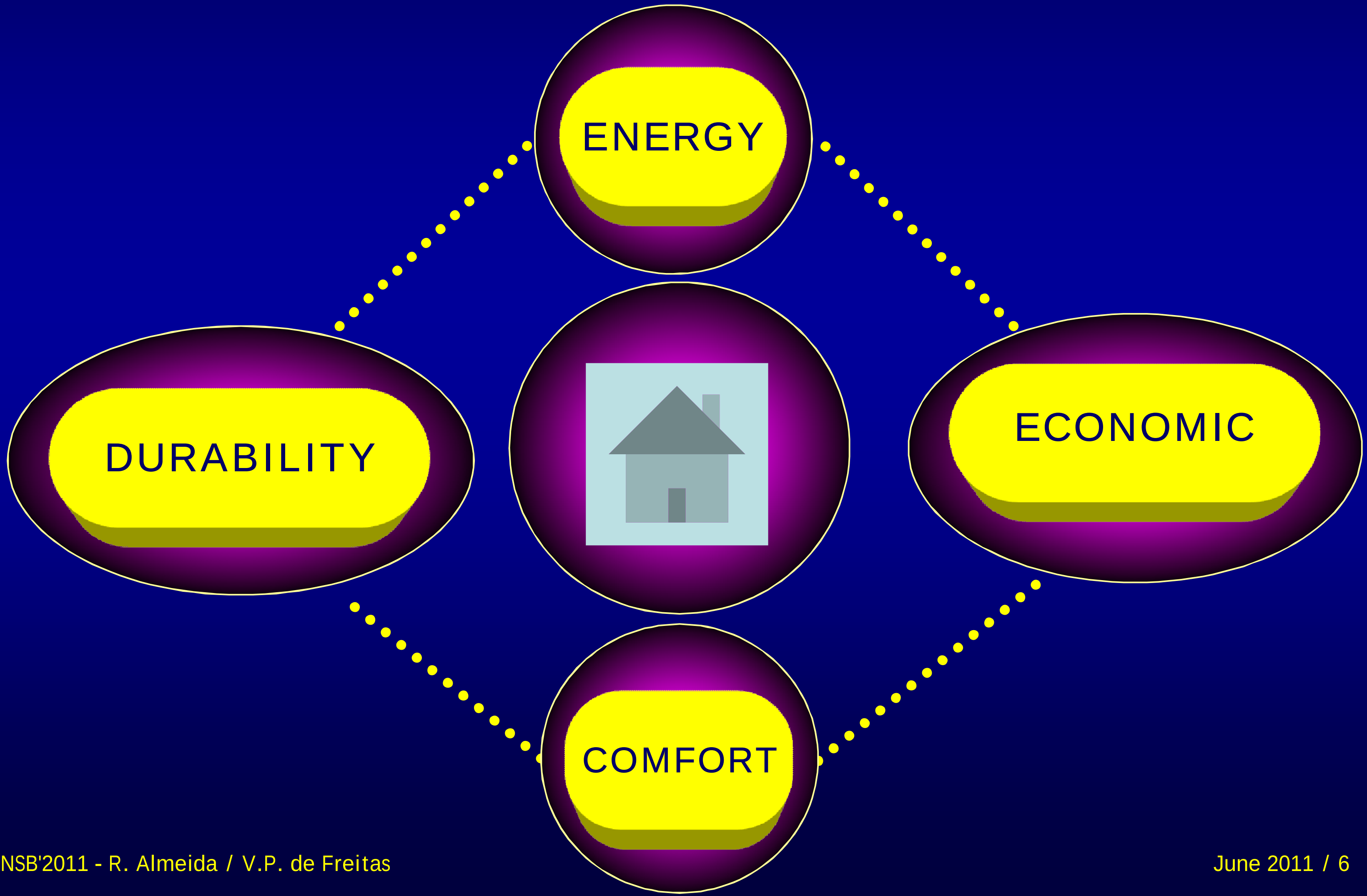
THE LBP RESEARCH PROJECT

MULTI-OBJECTIVE OPTIMIZATION WITH CONFLICTING OBJECTIVES



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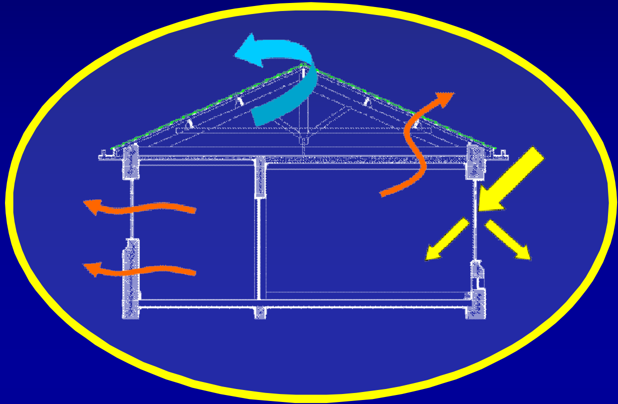
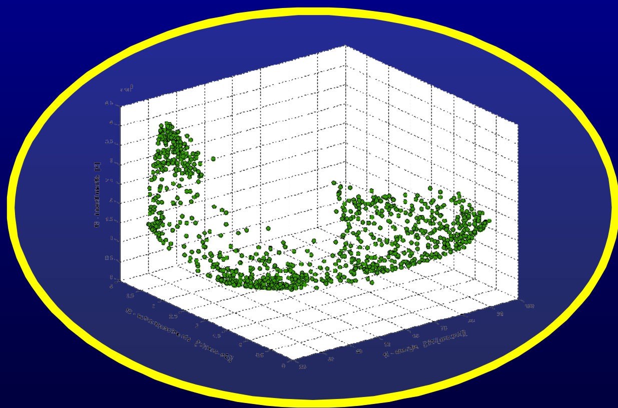
THE LBP RESEARCH PROJECT

CONSTRUCTIVE SOLUCTION



BUILDING SIMULATION

OPTIMIZATION



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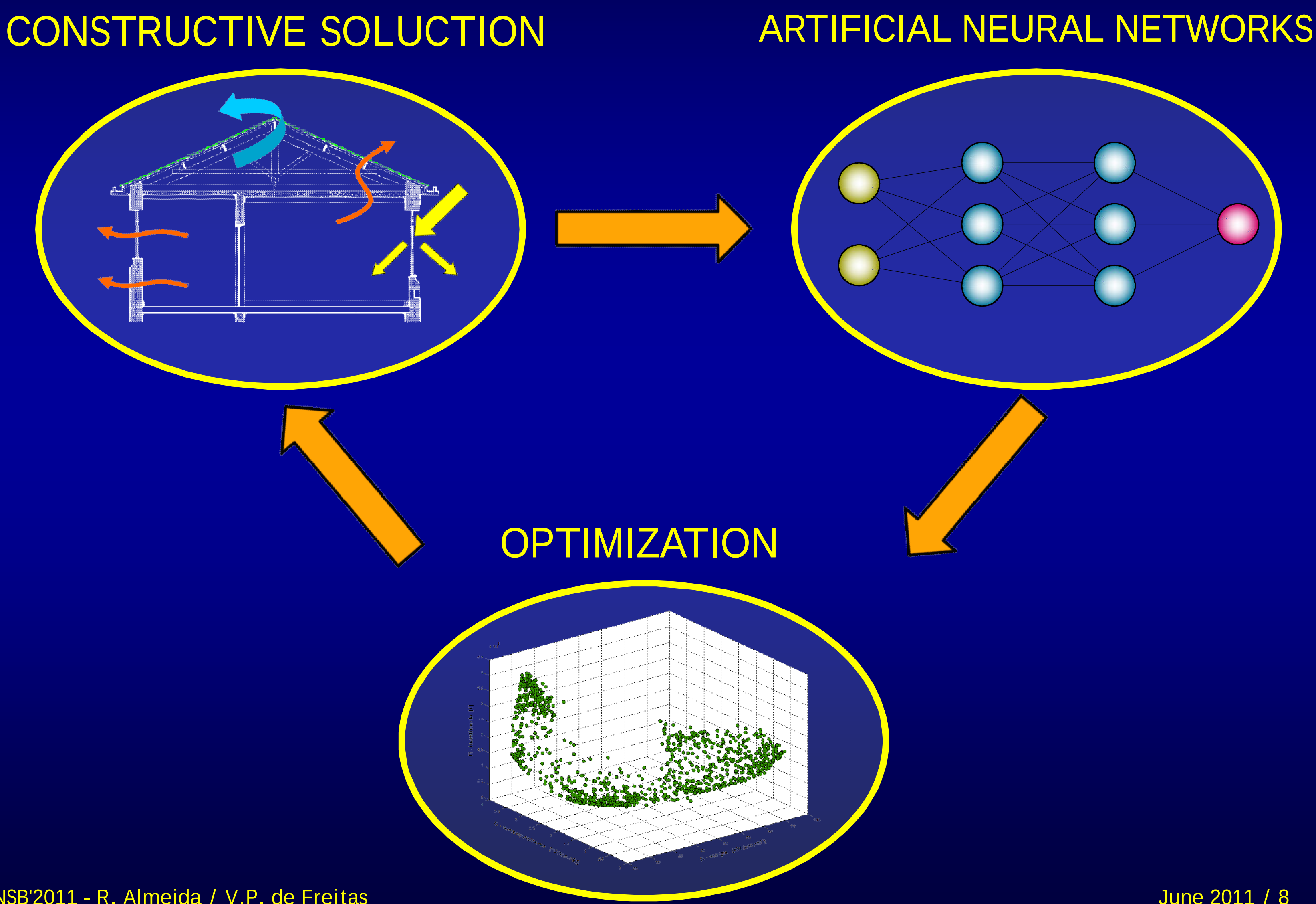

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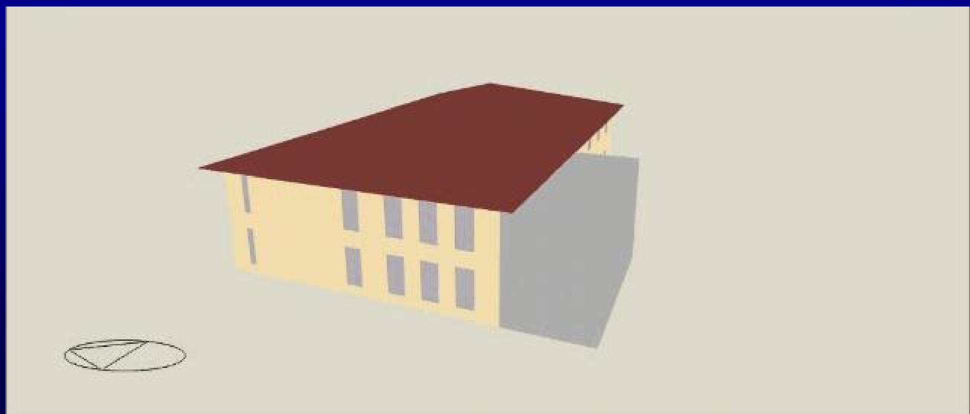
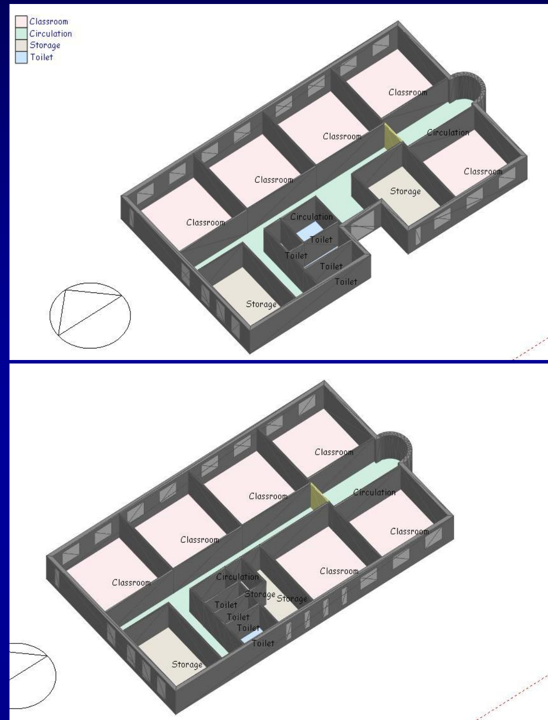
METHODOLOGY

METHODOLOGY - Model





- *No insulation*
- *Single glass*
- *No heating system*
- *Natural ventilation (window opening)*

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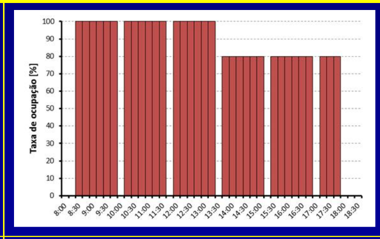
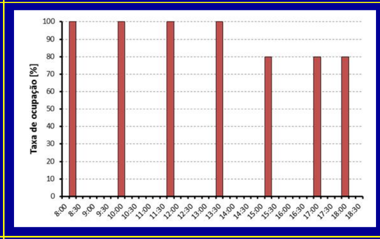
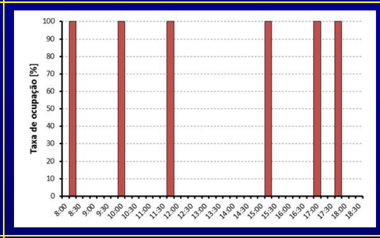
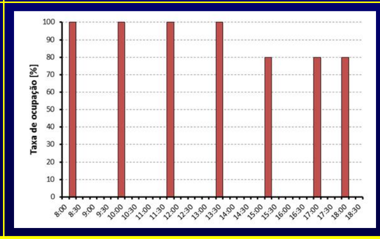
METHODOLOGY - Model

INTERNAL GAINS

Zones	Metabolic rate [W/person]	Density [people/m^2]	Occupancy profile (Monday to Friday)
Classroom	**94**	**0,40**	
Circulation	**112**	**0,60**	
Storage	**112**	**0,10**	
Toilet	**112**	**0,60**	

CONSTRUCTION

U_{walls} [W/(m^2.ºC)]	0,96
U_{roof} [W/(m^2.ºC)]	2,51
U_{window} [W/(m^2.ºC)	6,10
G_{window} [-]	0,81
ACR [h^{-1}]	0,25

EnergyPlus

- Annual simulations
- Hourly Outputs
- Model validation *(Almeida and Freitas, 2010)*

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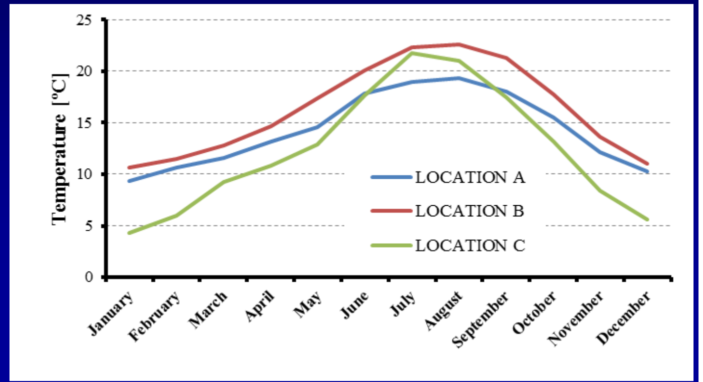
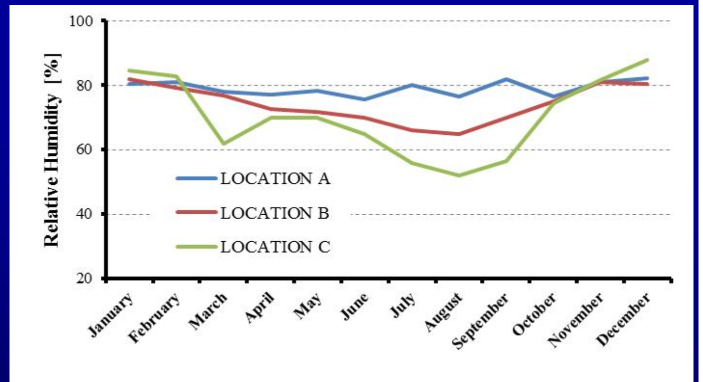
METHODOLOGY - Model

LOCATIONS





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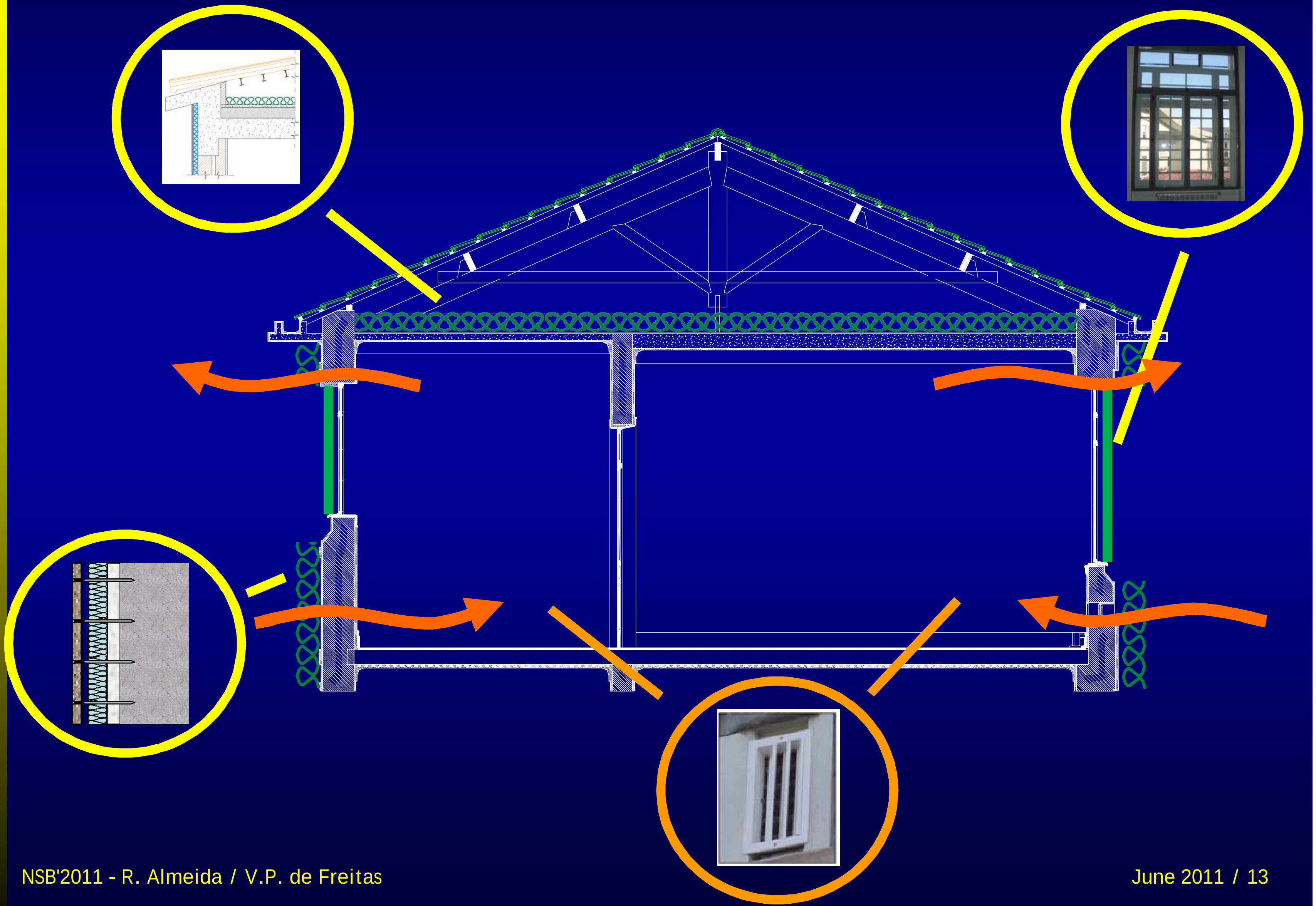
METHODOLOGY – Variables and performance functions



METHODOLOGY – Variables and performance functions

VARIABLES

	U_{walls} [W/(m^2.K)]	U_{roof} [W/(m^2.K)]	U_{window} [W/(m^2.K)]	G_{window} [-]	ACR [h^{-1}]
Actual	0,96	2,51	6,10	0,81	0,25
Maximum	1,80	3,00	6,10	0,90	5,00
Minimum	0,25	0,25	1,00	0,20	0,10

PERFORMANCE FUNCTIONS

$$f_1(U_{wall}, U_{roof}, U_{window}, G_{window}, ACR) = \frac{\sum_{year} H.L.}{S} \quad \wedge \quad T_{int} \geq 20^o C$$

$$f_2(U_{wall}, U_{roof}, U_{window}, G_{window}, ACR) = \frac{\sum_{year} (T_{int} - 25)}{S} \quad \wedge \quad T_{int} > 25^o C$$

Where :

H.L. - hourly heating load (kWh)

S - net floor area of the building (m^2)

T_{int} - hourly average interior temperature (ºC)

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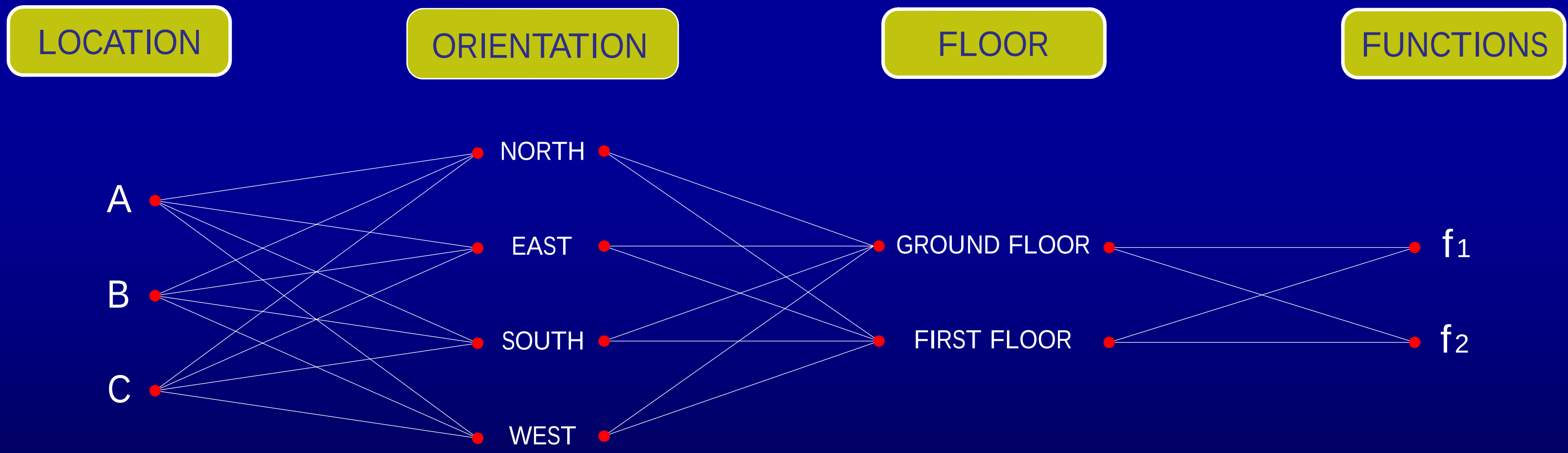
METHODOLOGY – Artificial Neural Networks (ANN)

1920 ANNUAL SIMULATIONS → 160 FOR EACH LOCATION AND ORIENTATION

- 150 for training
- 10 for validation

COMBINATIONS



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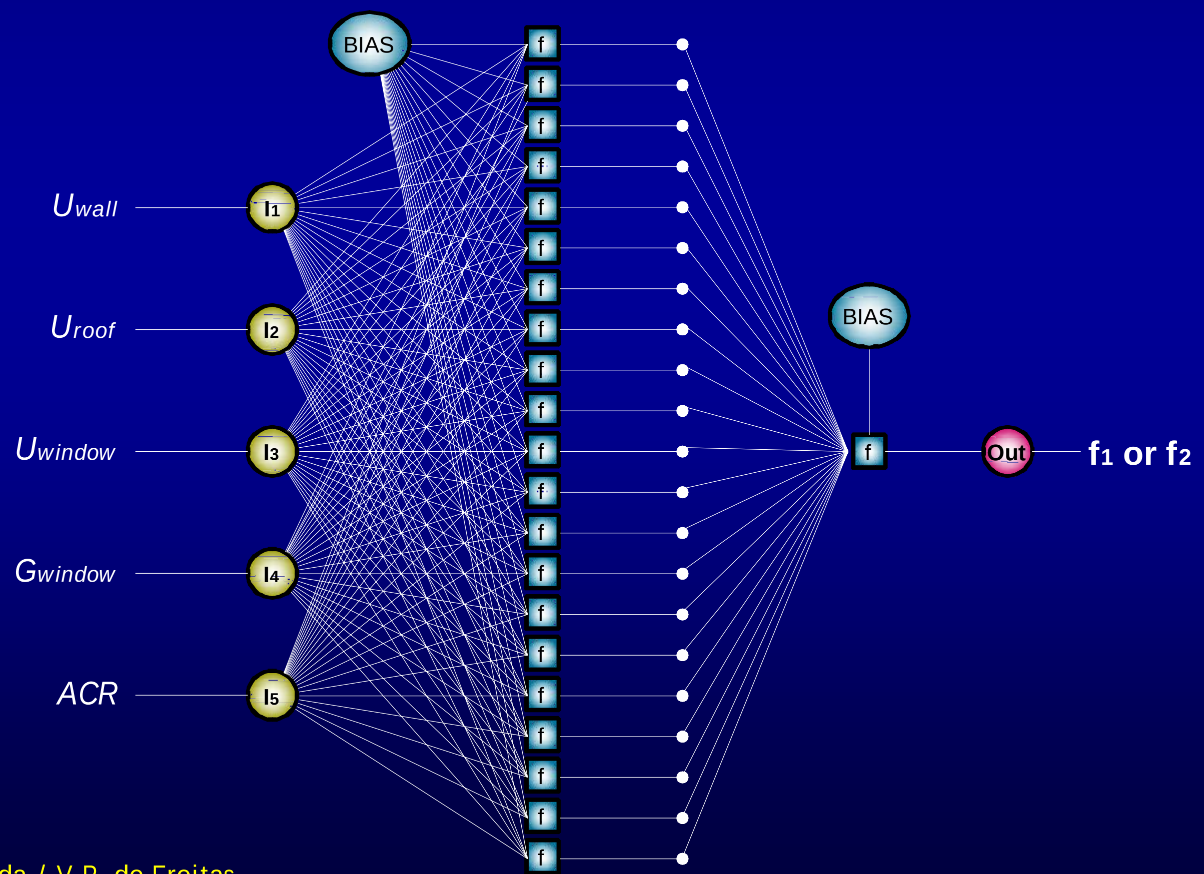
METHODOLOGY – Artificial Neural Networks (ANN)

ARCHITECTURE

- Multilayer feedforward with backpropagation
- 20 neuron, 5 input, 1 output
- Training algorithm: Levenberg-Marquardt with Bayesian regulation



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METHODOLOGY – Artificial Neural Networks (ANN)

VALIDATION

$$R^2 = 1 - \frac{\sum_{i=1}^{10} (y_i - p_i)^2}{\sum_{i=1}^{10} (y_i - \bar{y})^2}$$

		LOCATION A		LOCATION B		LOCATION C	
		f_1	f_2	f_1	f_2	f_1	f_2
N	GF	0.9990	0.9727	0.9989	0.9800	0.9990	0.9252
	1^{st} F	0.9976	0.9949	0.9969	0.9832	0.9983	0.9865
E	GF	0.9990	0.9766	0.9989	0.9784	0.9990	0.9045
	1^{st} F	0.9979	0.9840	0.9969	0.9864	0.9979	0.9899
S	GF	0.9990	0.9323	0.9988	0.9711	0.9990	0.9818
	1^{st} F	0.9980	0.9871	0.9963	0.9865	0.9978	0.9995
W	GF	0.9990	0.9751	0.9988	0.9719	0.9989	0.9868
	1^{st} F	0.9980	0.9886	0.9966	0.9670	0.9983	0.9962
MEAN VALUES		0.9984	0.9764	0.9978	0.9781	0.9985	0.9713
		0.9874		0.9879		0.9849	
		0.9868					

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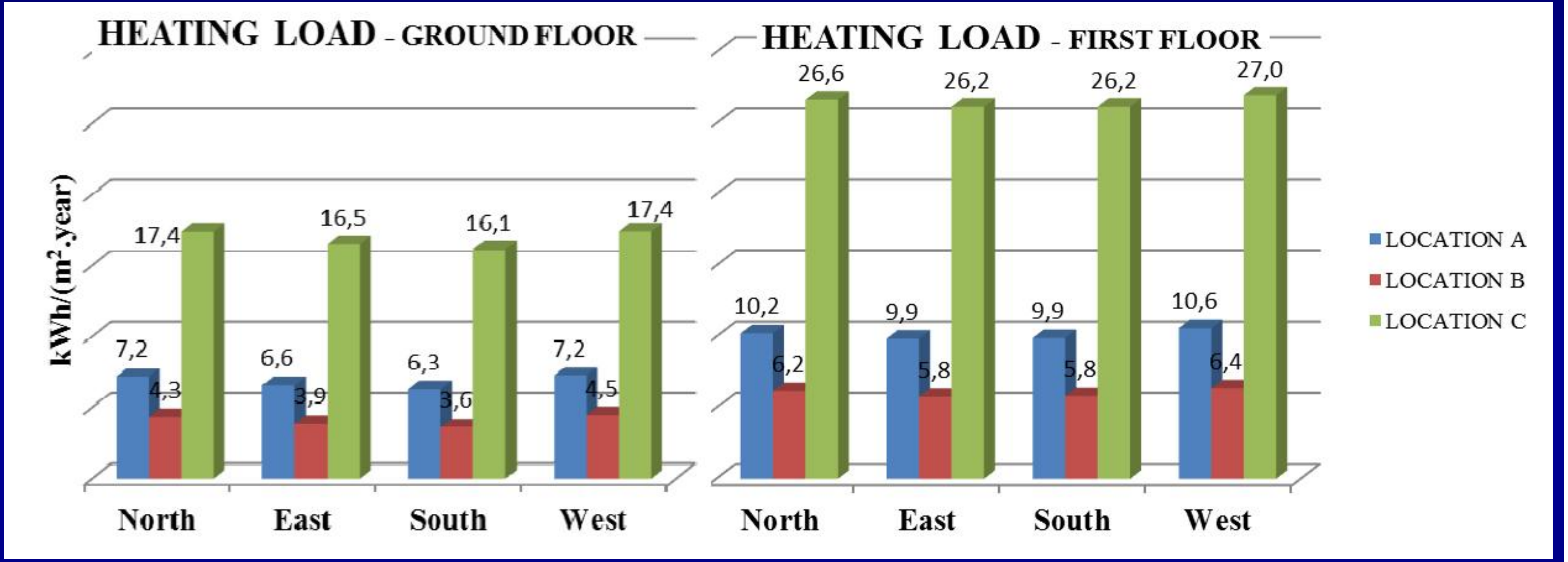
RESULTS AND DISCUSSION

RESULTS AND DISCUSSION – Evaluation of the school building performance

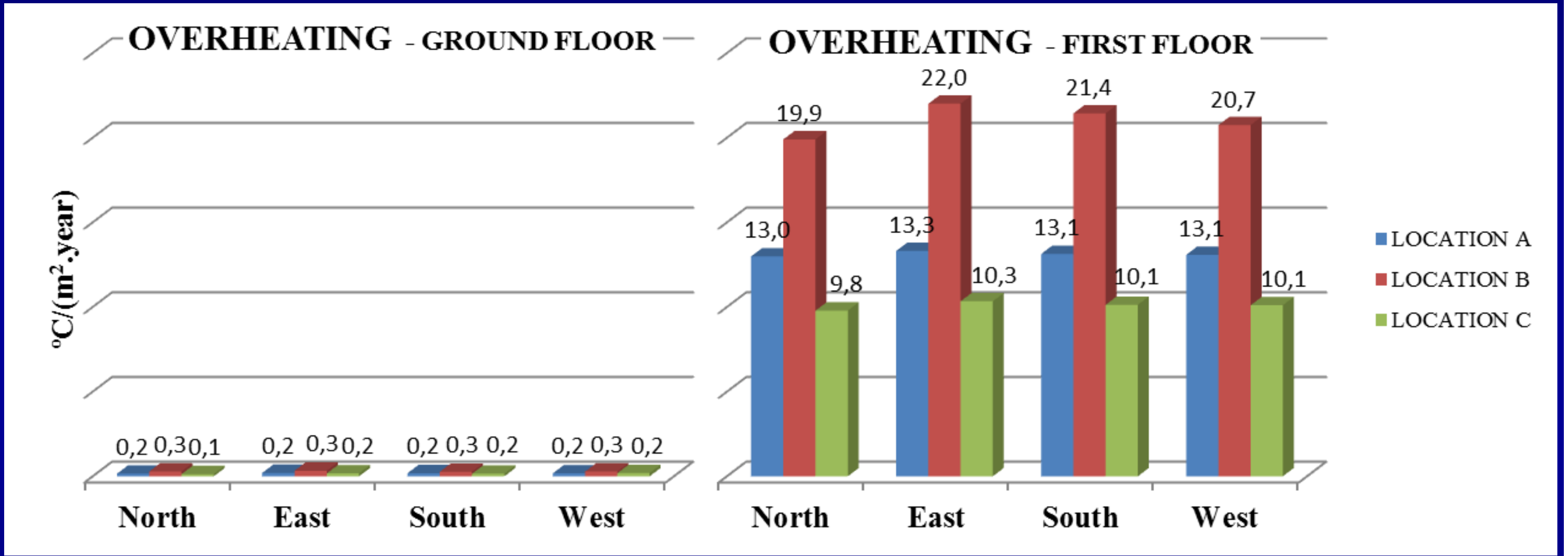
f_1 – Energy (heating load)



- Heating load higher in the first floor
- Heat losses through the roof are significant

RESULTS AND DISCUSSION – Evaluation of the school building performance

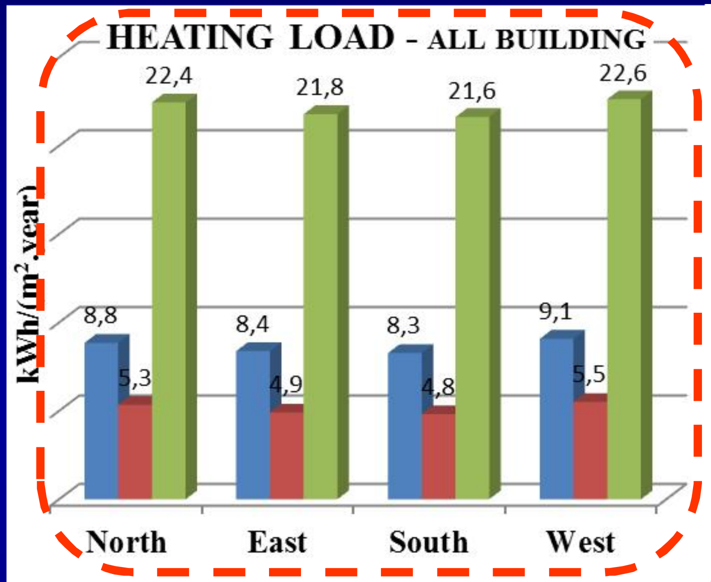
f_2 – Comfort (overheating)

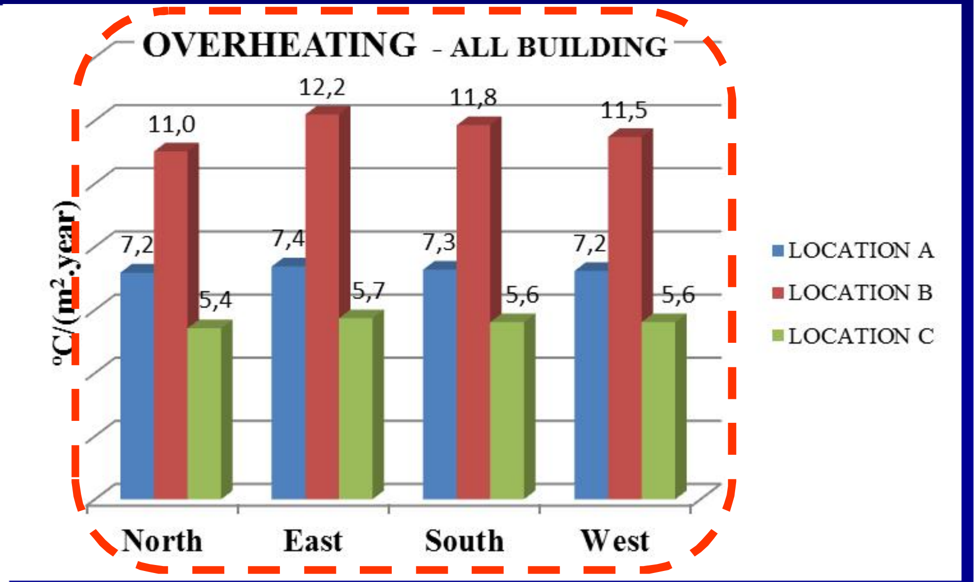


- Overheating is irrelevant on the ground floor

RESULTS AND DISCUSSION – Evaluation of the school building performance

Orientation

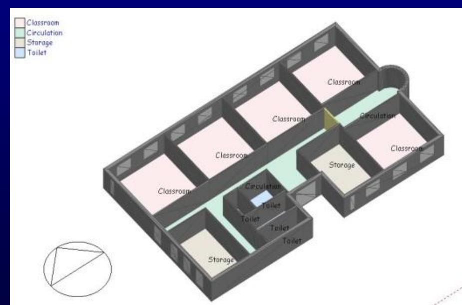




Mean difference
9.5%

Mean difference
6.4%

- Differences due to orientation
- Less energy required when facing South
- Less overheating when facing North



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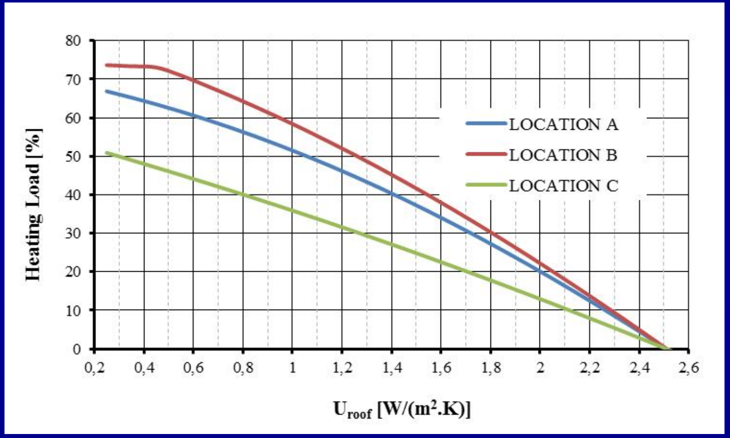
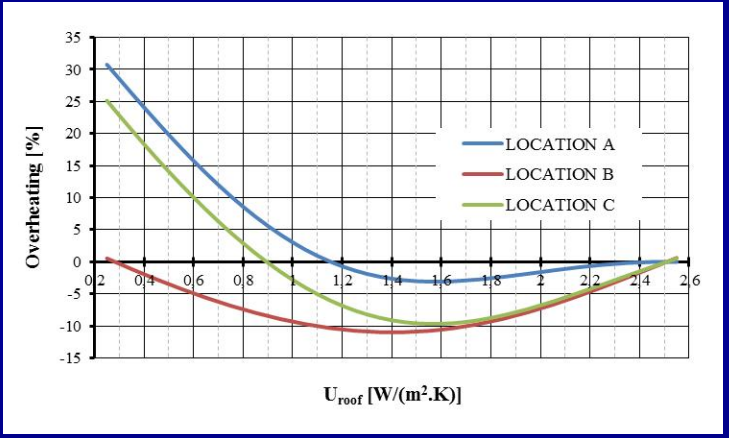
RESULTS AND DISCUSSION – Parametric optimization

IT WAS EVALUATED THE IMPACT OF EACH VARIABLE IN THE ALL BUILDING PERFORMANCE

Roof thermal coefficient

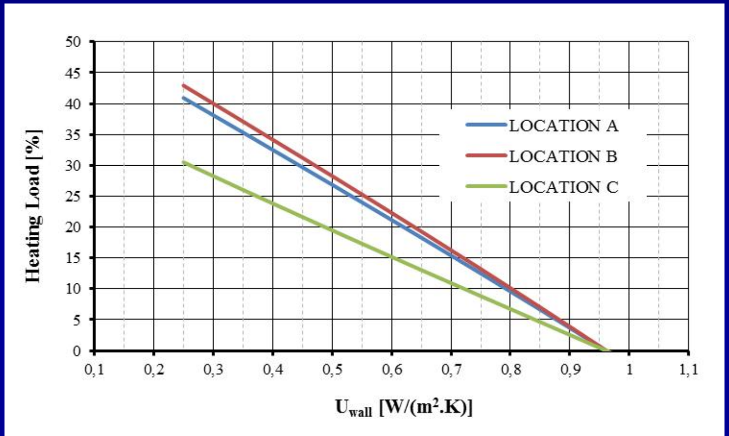


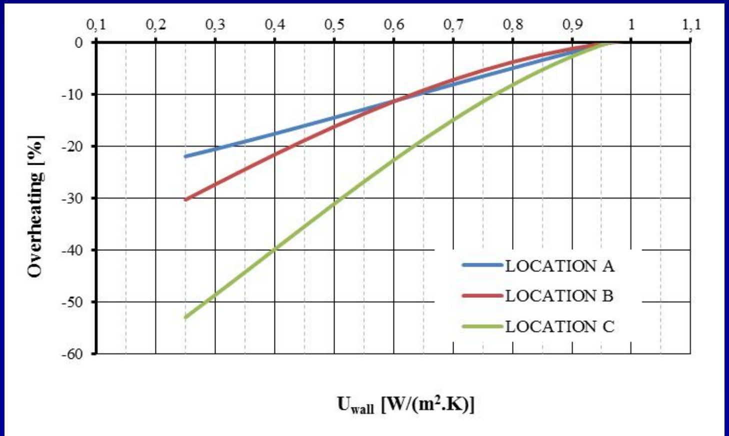


- Varying the insulation of the roof could decrease the heating load from 73%, in location B, to 50%, in location C
- In locations A and C this change also improve the summer comfort conditions of the building

RESULTS AND DISCUSSION – Parametric optimization

Wall thermal coefficient

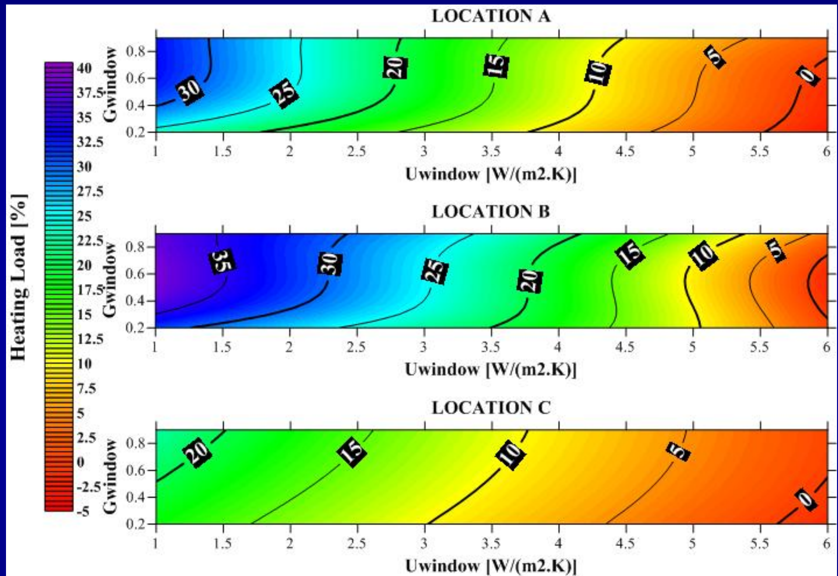


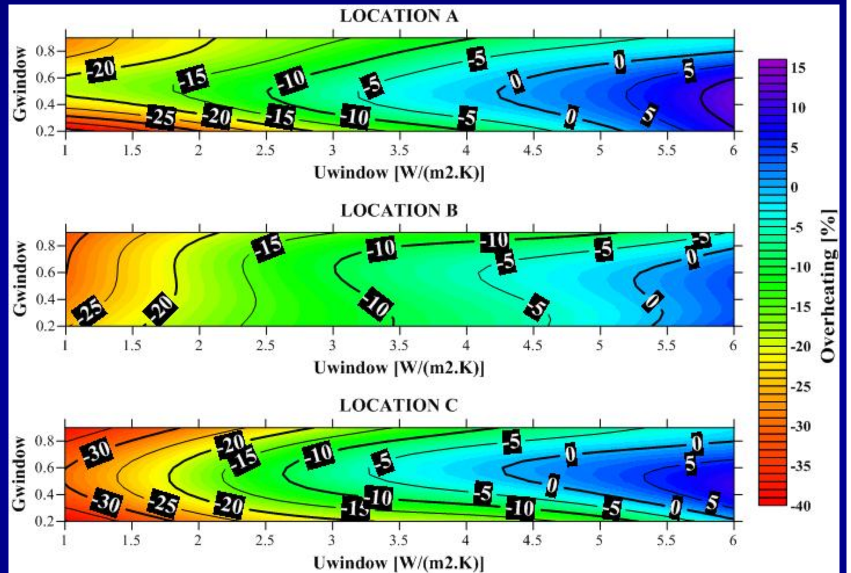


- Wall insulation could guarantee a reduction of up to 45% in the heating load
- But will be responsible for a decrease in the summer comfort conditions

RESULTS AND DISCUSSION – Parametric optimization

Window thermal coefficient and total solar energy transmittance

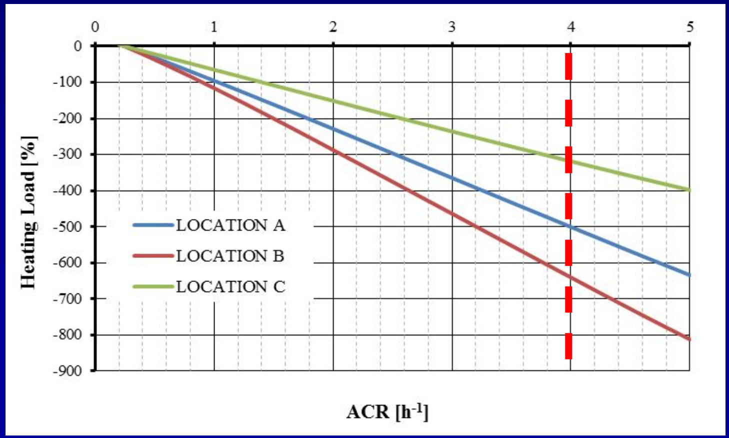


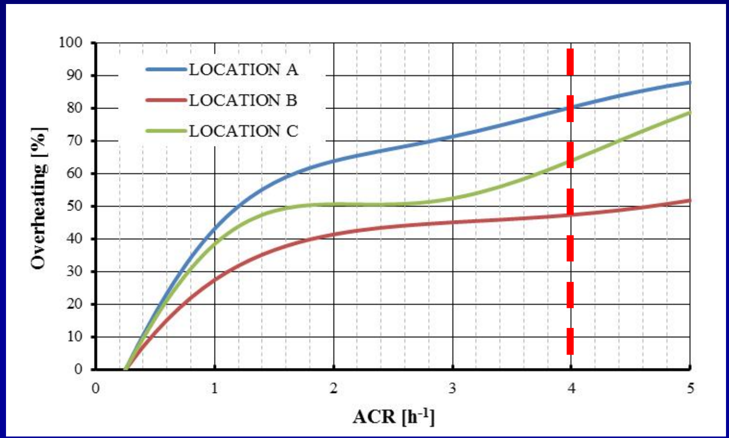


- Changes in windows are the most ineffective ones
- Although being possible to achieve a reduction of up to 30% in the heating load but the overheating problem will be intensified

RESULTS AND DISCUSSION – Parametric optimization

Air change rate





- A value of 4.0 h^{-1} in the ACR, minimum necessary according to the Portuguese legislation, implies an increase on the heating load that goes from 310%, in location C, to 640%, in location B
- Nevertheless the same change would decrease the overheating problem in 48%, in location B, and 80%, in location A.

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CONCLUSIONS AND FUTURE WORKS

CONCLUSIONS

MAIN CONCLUSIONS OF THE WORK

- Annual building simulation of complex models is a very time consuming procedure but necessary to understand the overall performance of the buildings
- ANN are a good instrument to estimate complex functions and can be used to substitute computer simulations, even though they require a significant amount of input data for training in order to achieve accurate approximations

CONCLUSIONS

MAIN CONCLUSIONS OF THE WORK

- The orientation of the building is responsible for significant changes in its performance
- The most effective retrofit measure to decrease the heating load is the roof insulation
- The ACR is the most important variable in the performance of the building

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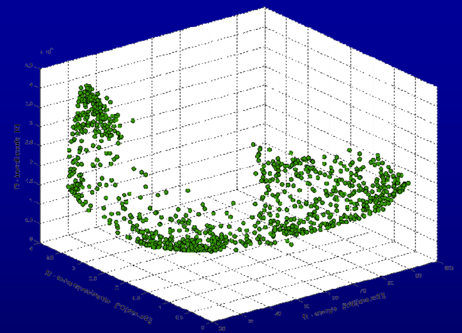
FUTURE WORKS

OPTIMIZATION OF CONSTRUCTIVE SOLUTIONS

MULTI-OBJECTIVE OPTIMIZATION USING EVOLUCIONARY ALGORITHMS



LIFE CYCLE ANALYSIS OF THE SOLUCTIONS

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THANK YOU FOR YOUR ATTENTION

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