EMPRICAL AND COMPUTATIONAL STUDY OF THE THERMAL PERFORMANCE OF A TRADITIONAL HOUSING TYPE IN KOSOVO

Albana Rexhepi, Ardeshir Mahdavi
Building Physics and Building Ecology
Vienna University of Technology, Austria

ABSTRACT

The present paper includes a study focused on the thermal performance of an instance of traditional (housing) buildings in Kosovo, known as Kulla. The study included both measurement of indoor-environmental (thermal) building performance and parametric simulation to study possible improvement scenarios. Five buildings were selected. Measurements showed that these buildings require no cooling. Annaul required heating energy is around 90 kWh.m^{-2}, which, with proper thermal treatment, could be reduced up to 70%.

INTRODUCTION

Kullas represent a special type of traditional housing in Kosovo. Apart from their cultural significance, Kullas have been regarded as having sustainable features in terms of climatic adaptation, energy efficiency, and the use of local materials. As a type of housing, Kulla appears in the beginning of the 18th century and it continued to be built until the later period of 19th century. Its development was influenced by social and cultural constraints as well as parameters related to availability of building materials and construction skills. At the present time Kullas are considered part of national cultural heritage and face, unfortunately, the danger of extinction.

Most available studies on Kullas are limited to historical and typological observations, neglecting the necessity of detailed physical study of their performance from the environmental point of view. In this context, the present study aims to investigate the thermal performance of this type of traditional housing both in their current conditions and under the assumption of possible improvements. The study involved the following:

a) Long-term monitoring of thermally relevant indoor environmental conditions in selected buildings in the region of Dukagjini, Kosovo;
b) Evaluation of the existing indoor climate conditions based on the monitoring results;
c) Generation of calibrated simulation models of these buildings;
d) Simulation-based comparison and evaluation of alternative thermal improvement scenarios for the selected buildings.

APPROACH

Case studies

Five buildings were selected as subject of this study (see Figures 1 to 10). They were categorized depending on being fully occupied, partially occupied, or not occupied.

Table 1 Overview of selected buildings

Code	K1	K2	K3	K4	K5
Approximate date of Construction	1800	1810	1800	1825	1850
Total floor area [m²]	228	263	303	183	220
Occupancy	Partial	Non	Full	Non	Partial

A long-term data monitoring campaign was carried out in these buildings. In four buildings measurements were conducted from August 2008 to July 2009, in one building measurements could be conducted for 3 months only (August 2008 to December 2008). Ten data-loggers collected periodically (every 15 minutes) information regarding indoor air temperature [°C], relative humidity [%], and illuminance [lx]. The loggers were placed in different spaces inside buildings (living room, fire room, ground floor hall). External weather data was provided from local meteorological station in Prishtina, (IHMK 2008-2009). Since this data was not detailed enough, it was combined with synthetic weather files (generated via Meteotest 2008).

Figure 1 Exterior view of building K1

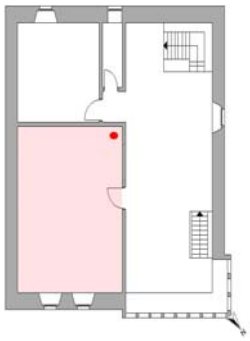

Figure 2 Building K1, view of typical floor plan with sensor position; fire room 3rd floor

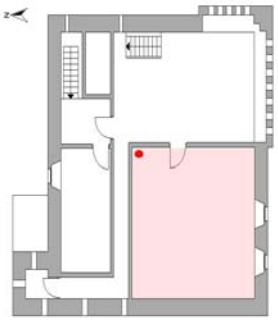

Figure 3 Building K2, view of typical floor plan with sensor position; fire room 3rd floor

Figure 4 Exterior view of building K2

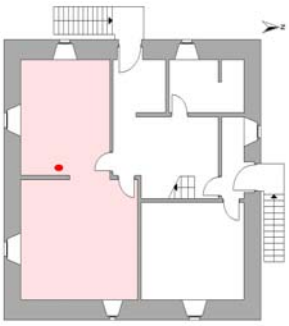

Figure 5 Building K3, view of typical floor plan with sensor position; living room 3rd floor

Figure 6 Exterior view of building K3

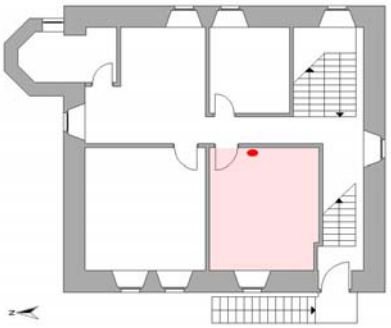

Figure 7 Building K4, view of typical floor plan with sensor position; living room 4th floor

Figure 8 Exterior view of building K4

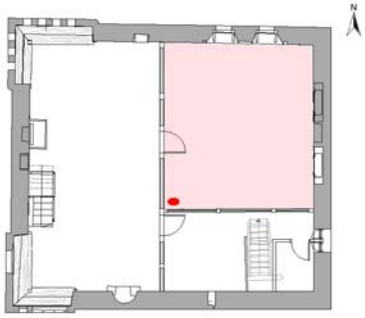

Figure 9 Building K5, view of typical floor plan with sensor position; fire room 3rd floor

Figure 10 Exterior view of building K5

Measurements data analysis

Collected data was analyzed and interpreted in view of the building's thermal performance and comfort conditions. Monitored indoor conditions were depicted in terms of psychrometric charts, which include comfort zones as per the adaptive thermal comfort theory (Szokolay 2007). Additionally, PMV and PPD values (Fanger 1970) were derived based on measurements and auxiliary assumptions regarding occupants' activity and clothing.

Calibration of Simulation Models

Measurements of indoor thermal parameters in the buildings not only inform about Kullas' current thermal performances, but also facilitate simulation model calibration (Mahdavi at al. 2004). However, simulation calibration requires also detailed weather information. Weather files from local weather station in Prishtina (IHMK 2009) did not contain sufficient data. Thus, available local weather information was compared with a detailed synthetic weather file for the region (generated using Meteotest 2008). As a result, periods in detailed weather file could be identified, which sufficiently resembled measured data. Such periods were then used for the simulation calibration process. To illustrate this point, Figure 11 shows for a sample day (out of the period selected for simulation calibration), the outdoor air temperature as measured by the local Weather Station in Prishtina versus the Meteotest data.

To illustrate the performance of the calibrated simulation model, Figures 12 to 15 show measured and simulated indoor air temperatures in buildings K1 to K4 for a day out of the calibration period.

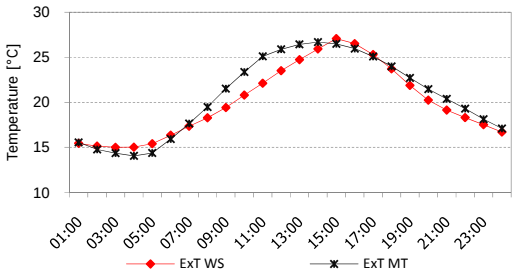

Figure 11 Comparison of external temperature from weather stations file (WS)and meteotest (MT), in a segment from the time period selected for model calibration

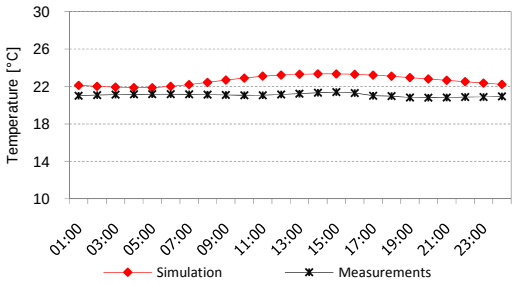

Figure 12 Comparison between simulated and measurements results for K1

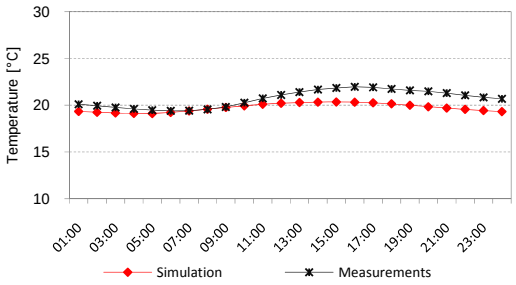

Figure 13 Comparison between simulated and measurements results for K2

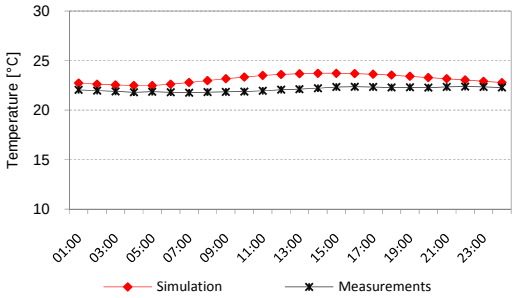

Figure 14 Comparison between simulated and measurements results for K3

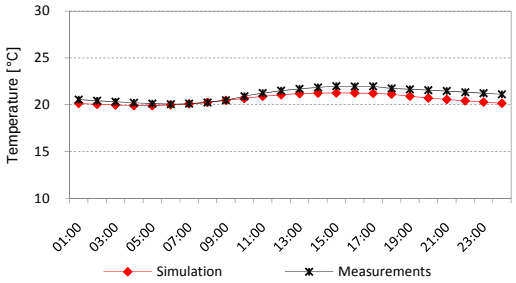

Figure 15 Comparison between simulated and measurements results for K4

Parametric Simulation

A base case (BC) and two improvement scenarios (S1, S2) were considered for parametric simulations. Table 2 includes construction information for the base case scenario representing the assumed existing state of the buildings. Table 3 shows the first thermal improvement scenario. Thereby, the windows' glazing was virtually replaced with low-e triple glazing. Moreover, the thermal insulation of the roof was improved in this scenario. Table 4 shows the second thermal improvement scenario, which adds the thermal insulation improvement of the external walls to the first scenario. Given the historical status of these buildings, thermal insulation improvement cannot be performed on the façade. Insulation panels must thus be installed on the inside of the external walls. As this solution might cause condensation inside the walls, a preliminary computational examination of the condensation risk was conducted. The results suggest that such risk is not critical. Table 5 summarizes (for BC, S1, and S2) the internal loads (people, lighting, and equipment), assumed air change rates, and the applicable room set point temperatures.

Table 2 Overview of the base case (BC) Simulation Scenario

BUILDING	DESCRIPTION
K1, K3, K4, K5	U_{Wall} = 2 W.m^{-2}.K^{-1} ; U_{Window} = 2.9; U_{Roof} = 0.5; g = 0.75
K2	U_{Roof} = 2 W.m^{-2}.K^{-1}; U_{Window} = 5.8; g_{Window} = 0.85

Table 3 Overview of the first improvement scenario (S1)

BUILDING	DESCRIPTION
K1 to K5	U_{Window} = 0.96 W.m^{-2}.K^{-1}; U_{Roof} =0.18 ; g = 0.55

Table 4 Overview of the second improvement scenario (S2)

BUILDING	DESCRIPTION
K1 to K5	U_{Window} = 0.96 W.m^{-2}.K^{-1}; U_{Roof} = 0.18; g = 0.55; U_{Wall} = 0.3

Table 5 Summarized internal gains, air change rate, and temperature set points, (BC)

	Buildings				
	K1	K2	K3	K4	K5
Internal Gains [W.m^2]					
Occupants	0.3	-	-	-	-
Lighting gain	7.5	-	5.6	6	7.4
Air change rate [h^{-1}]	0.6	0.6	0.6	0.6	0.6
Temp. set points [°C]					
Rooms	20	20	20	20	20
Bathroom	22	22	22	22	22
Staircase-hall	16	16	16	16	16

RESULTS

Evaluation of the existing indoor conditions

Figures 16 to 19 depict measured indoor conditions (in K1, K3, and K4) in terms of psychrometric charts (for July 2009).
Table 6 shows derived mean monthly PPD values in K1, K3, and K4.

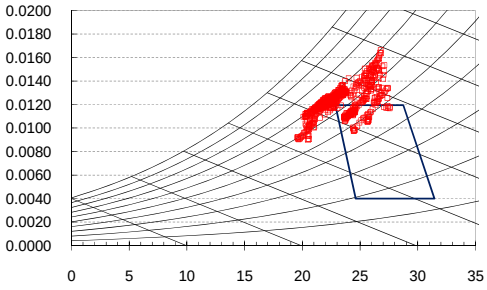

Figure 16 Psychrometric chart, fire room, K1 (partially occupied), July

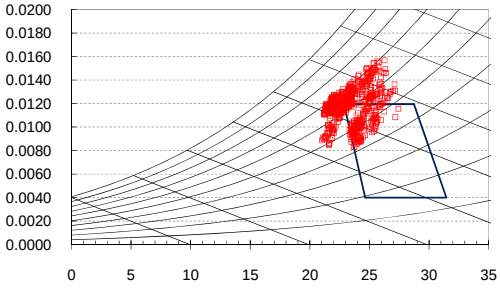

Figure 17 Psychrometric chart, living room, K3 (fully occupied), July

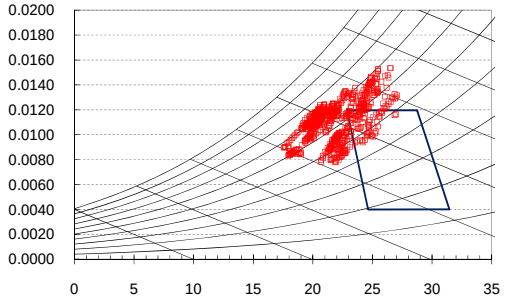

Figure 18 Psychrometric chart, living room, K4 (non occupied), July

Table 6 Mean monthly PPD [%], buildings K1, K3, and K4; non, full and partially occupied

	Buildings/Rooms					
	K1		K3		K4	
Month	LR	FR	LR	FR	LR	FR
August	6.3	10.6	8	11.2	9.7	-
September	46.7	48.8	20	57.5	57.1	-
October	58.5	55.5	33	74.9	68.7	-
November	36.2	26.3	11.6	39.4	38.1	-
December	99.1	95.2	25.7	97.7	99.8	-
January	99.9	99.9	26.2	99.4	99.9	-
February	99.9	99.9	14.3	99.8	99.9	-
March	99.7	99.7	34.2	93.2	99.9	-
April	87.4	84.9	35.8	92.5	93.9	-
May	56.6	45.1	19.4	47.9	57.6	-
June	44.8	39.6	26.2	44.4	55.2	-
July	-	13.6	10	16.6	22.9	-

Simulation results

Figure 19 shows simulated indoor temperature in K3 (living room) for the year's warmest day (21st of July, 2009).

Figures 21 to 25 illustrate the simulated heating loads for all buildings and scenarios (BC, S1, and S2).

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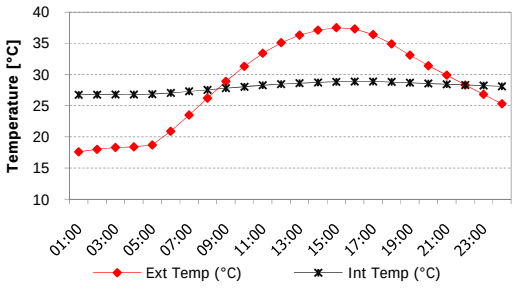

Figure 19 Simulated indoor temperature (21st of July, 2009), K3, living room, together with the external temperature data from the weather file

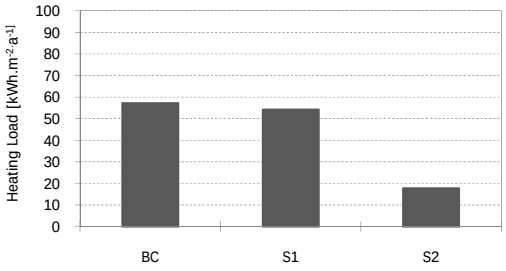

Figure 20 Simulated heating loads for building K1

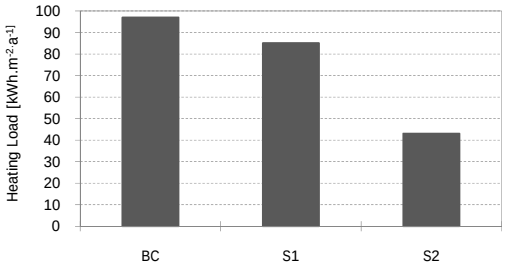

Figure 21 Simulated heating loads for building K2

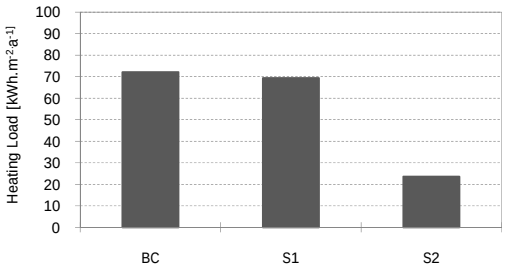

Figure 22 Simulated heating loads for building K3

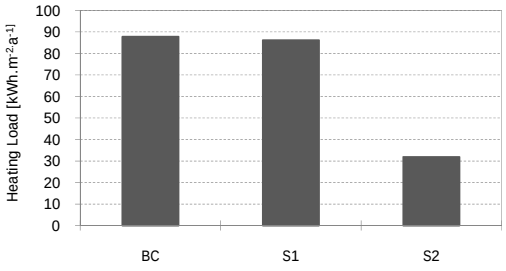

Figure 23 Simulated heating loads for building K4

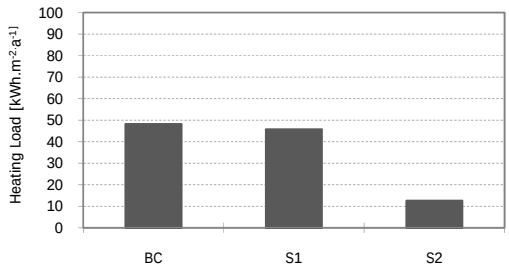

Figure 24 Simulated heating loads for building K5

DISCUSSION

The results of the thermal comfort analysis with psychrometric charts suggest that during the warmest month of the year (July) indoor air temperatures in Kullas stay well below the upper bound of the recommended comfort temperature. In fact, PMV estimations suggest that even in summer the buildings' indoor conditions are perceived as slightly cool, or cold.

Simulated indoor conditions during the year's warmest day (21st of July, 2009) illustrate the effect of the building's high thermal inertia (Figure 19). While external temperature reach a peak value of 37.5 °C, indoor air temperature in the living room (K3) fluctuated very little and stayed under 29 °C.

As to the parametric simulations of heating loads, improvement potential due to better window and roof insulation brought about, compared to the base case, only a modest reduction of the calculated heating loads (2 to 12 %). The main reason for this circumstance is the relatively small fraction of window and roof areas compared to the total area of the building envelope.

Once the external walls are included in the improvement scenario (S2), a much higher heating load reduction potential is revealed (60 to 75%).

Future studies will explore a richer set of thermal improvement options for parametric simulation runs. Moreover, the potential for active solar energy gain through solar collectors and PV cells will be examined toward coverage of the buildings electrical power and heating energy requirements.

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