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ADAPTABILITY OF BUILDINGS TO CLIMATE CHANGE AND ENSURING COMFORT UNDER SUMMER CONDITIONS

BY

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Abstract. The impact of climate changes occur not only on environmental systems but also on social systems and life quality. Thus, to eliminate costs associated with adverse effects onclimate change at global and European level, policies are developing setting aim to cease causes through mitigation and reduce vulnerability by an increase in the capacity of adaptation to new challenges. Within this policies, an important role is held by the building sector given that actions such as overheating spaces where people live and conduct different activities may have negative consequences on comfort and human health. Passive measures that contribute to increased adaptability of buildings target thermal massiveness, optimized ventilation, passive cooling systems, adoption of green surfaces, and not least, alter human behavior. This paper presents a case study on two single-family houses with similar geometric and energetic characteristics but different in terms of thermal massiveness. The analysis based on the principles of adaptive comfort concept highlights that thermal massiveness contributes to increased adaptability of buildings to climate change.

Key words: adaptability; adaptive comfort; climate change; operative temperature.

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1. Introduction

Climate change caused by massive atmospheric greenhouse gases, deforestation, changing water courses and other human activities with disastrous impact on the environment have become a certainty, as that the process can not be stopped on short or medium term. The negative effects are felt not only on natural and human systems but also on the socio-economic and, therefore, the associated risks claim a wide range of commercial policies and strategies at local, regional and global level (www.teriin.org/events/docs/adapt).

In the EU agenda, the impact of climate change on the natural environment at regional level and what political instruments are available for mitigating the effects occupies a very important position (Indicator-based report 2012; Commission of the European Communities, 2008).

Previously conducted studies highlight that more than a third of the European Union population, 170 million people, live in regions most affected by climate change, the greatest risk recorded throughout Spain, Italy, Greece, Bulgaria, Cyprus, Malta, Hungary, much of Romania and the south of France. The extent to which different regions of Europe are likely to be affected was quantified by an index of vulnerability to climate change as presented in Fig.1.

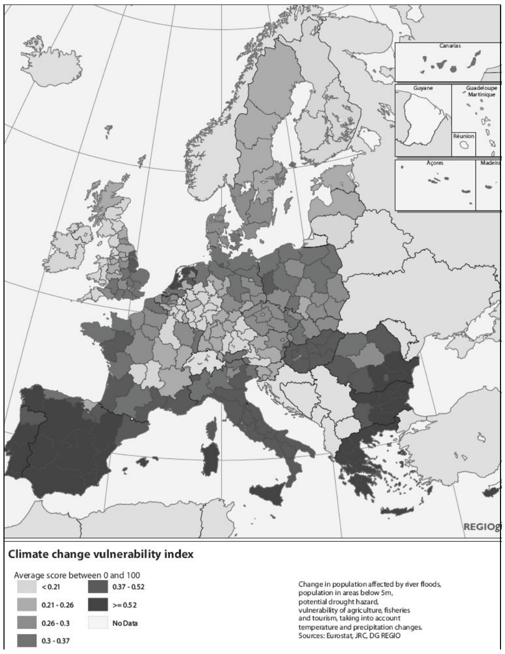

Fig. 1 – Climate change vulnerability index, *EU Report 2020* (2008).

Conclusions of the *EU Report 2020* studies point out that adaptation to climate change is vital, severity of this impact depending on physical vulnerability, level of economic development, human and natural adaptive capacity, health services and regulation mechanisms.

UNFCCC (*United Nations Framework Convention on Climate Change*) draws two directions that include fundamental strategies to climate change: mitigation and adaptation. While *mitigation* is aimed at limiting and reducing the causes of climate change, through radicalization and diversification measures to reduce greenhouse gas emissions, *adaptation* seeks to reduce the aggressively impact of climate through a wide range of actions and specific measures.

2. Impact of Climate Change on the Built Environment

Regarding the relationship between buildings and climate change, it can be stated that is is complex, with a strong synergistic feature, considering the following aspects:

a) buildings interfere with an important share in the production of greenhouse gas emissions (40% in Europe), thus contributing to the process of climate change;

b) the impact of climate change on buildings can not be ignored, manifesting itself both at the structural level and directly related to user behavior, at extent to which proper indoor environmental quality could be ensured (air quality, thermal comfort, visual comfort, etc.);

c) the impact of climate change on buildings behavior is manifested in particular by increasing summer temperatures and therefore difficult to achieve comfort conditions without additional energy consumption; this leads to mitigation measures for energy conservation and emission reduction in greenhouse gas emissions;

d) in most cases, measures to reduce energy consumption, properly managed, contribute positively to the response of buildings regarding climate change.

In this context, the attitude of professionals in building design and construction industry to climate change it is particularly important, to report concerns about mitigation – adaptation becomes a priority.

Relevant in this regard is the project *“Establishing research direction in sustainable building design”* developed at the *Tyndall Center for Climate Change Research* in the years 2001 – 2002 (Project Overview, 2001–2002) under the leadership of Dr. Koen Steemers from *Martin Centre for Architectural and Urban Studies, University of Cambridge*. The objective of this project was to develop the program for the future research agendas and included as participants research centers and universities with recongnized achievements in the field from Europe and America as well as industry representatives and users. The conclusion formulated after the workshops and discussions conducted emphasize as most appropriate response to climate change the development of the adaptive capacity of buildings and urban form, in close correlation with measures to mitigate climate change.

On the same lines enscribes the results of an entire series of studies conducted under the guidance of Professor Steemers, from *Tyndall Center*, which hihglights that developing strategies to combine measures to mitigate the causes of global warming with adapting to climate change at urban unit, building and individual level, is the main direction integrating the research aspect in the construction sector, which should ultimately lead to significant changes for addressing sustainable design (Steemers, 2005, 2002, 2001).

Regarding the definition and introduction of adaptability of buildings to climate modifying trials were conducted with concrete objectives regarding the impact on buildings closely correlated with the urban and local geo-climatic context. The *Worcester Climate Change GroupParteners* (Hacker & Holmes, 2007) indentifies four main sectors sensitive to climate change:

a) the built environment/ infrastructure;
b) industry and trade;
c) public services;
d) natural environment.

The study selected as interest areas, zones in which these sectors can be considered vulnerable and estimate what their impact might have on the expected climate change predictions. Recommendations are formulated regarding the most appropriate adaptive measures for each sector analyzed.

Hacker and Holmes (2007) examine the implications for two types of adaptive solutions – passive cooling and air conditioning – in several major cities in the UK, taking into account the evolution of climatic parameters predicted by *UKCP02 Medium-high Emission Scenario*. Conclusions from this study reveal that London presents a higher overheating risk than Manchester, due to increased density of the built environment within the city. The Urban Heat Island phenomenon occurring in metropolitan regions worldwide highlights the need to adapt buildings for future climate conditions, specifically as the above mentioned study reveals, adopting low-energy and sustainable design principles.

Adaptability to climate change as a priority requirement of existing buildings on performance satisfaction criteria related to indoor environment and sustainable development, is analyzed by P.A. Bullen, based on a study regarding the background of commercial buildings in Western Australia (Bullen, 2004). The contribution brought by this study consists in identifying how relevant is user behavior regarding adaptability in terms of pronounced variability of environmental conditions triggered by climate change.

In this context, an essential criterion is the level of occupants satisfaction with applying adaptive model of comfort condition assessment recommended by ISO, CEN, ASHRE. Compared to Fanger model, the adaptive model provides design criteria for superior comfort by taking into account user behavior while providing significant energy savings during the hot season.

3. Summer Comfort Under Increased External Temperature; Measures to Increase Buildings Adaptability

The evolution of summer temperatures from recent years registered in Romania acknowledge findings from studies conducted in developed countries regarding climate change phenomenon while feedback from building operation confirm a low existing degree of adaptability in this context. Therefore, buildings with deficient adaptability lead to an increase in cases of uncomfortable situations in terms of indoor environment, with negative effects on human health and raised energy consumption due to air conditioning installations devices.

A study by scientists Rajat Gupta and Matt Greg (2013), implemented in the UK aimed at analyzing the risk of overheating as a result of probabilistically estimated climate change scenario between 2020 – 2050 for dwellings located in the suburbs of three major cities: Brixtol, Oxford and Stockport. Conclusions following this analysis highlights the main factors responsible with risk of overheating as well as strategies to increase buildings adaptability, resulting from combining optimization measures of architectural – constructive solutions with reduced internal heat input. Passive measures against overheating scenarios in buildings, obtained through simulation or field study and which conclude the analysis are presented in Table 1.

In an attempt to synthesize existing scientific literature and case studies regarding climate change and adaptability incentives, the following aspects can be highlighted:

a) the built environment is affected by the impact of climate change, contributing at the same time essentially to these changes;

b) despite variability, climate change and as far as they affect existing buildings, in the principles of sustainable development, can be predicted with a sufficient level of confidence;

c) strategies to increase the level of adaptability can be integrated into Sustainable Development so far as they contribute to extending the life cycle of the building;

d) estimating the level of adaptability can not ignore the behavior and level of user satisfaction as well as the dynamics of the assessment indicators.

Table 1
Passive Measures that Have Been Shown To Reduce Temperature
(adapted from Gupta R. and Gregg M., 2012)

Passive measures		Hot, arid climates	Hot, humid climates	Projected English climates	Tested at home scale (IES VE)[f]
Personal					
Remove clothing (reduce clo-value)		Measures known to be effective in reducing the risk of heat related stress or worse (National Health Service (NHS), 2012)			
Increase hydration					
Use water to assist the skin with thermoregulation					
Seek a cool refuge outside of the home					
Home and proximity					
Day-time cross ventilation (open-windows)		x[a]		x	x[e]
Night ventilation		x	x[b]	x	x[e]
Reduce internal gains				x	X
Shading	Trees or deciduous vegetation	x	x	x	
	External shading devices (louvers, fixed porches)	x	x	x	X
	Internal shading devices (curtains and blinds)			x	
External wall insulation				x	X
Loft insulation				x	X
Floor insulation					X
Dereased floor insulation (limited to the perimeter)			x		
Solar selective e-low glazing				x	
High albedo surfaces		x[c]	x	x	X
Thermal mass		x	x[d]	x	
Passive ground cooling			x		
Passive downdraught evaporative cooling		x			
Enclosed courtyard		x	x		

Notes:
[a] At times the air can be so hot that daytime ventilation is not possible.
[b] Dehumidification required at times.
[c] Greater impact in hot, arid climates.
[d] Thermal mass was found to be effective in some instances; however, night ventilation purging is essential and effectiveness would depend on the stability to night-ventilate.
[e] Ventilation was already a consideration in the overheating analysis as it is assumed occupants already do this mitigate overheating.
[f] Integrated Environmental Solutions – Virtual Environment.

4. Study Case Analysis

In order to analyze the level of adaptability to climate change and highlight key determinant factors for specific climatic conditions in Romania, the team considered a study case on two single family housing with approximately the same level of thermal insulation.

Criteria considered for analysis are as follows:

a) specific annual energy demand for cooling in order to maintain an indoor air temperature value, T_i of maximum 26°C;

b) annual number of cooling hours;

c) extent to which compliance of adaptive comfort during hottest times of the year is met.

Building A represents a dwelling with a ground floor and a ventilated attic. The volume dwelling inscribes in a parallelepiped with a foot print of 19 m by 15 m with a level height of 3 m, schematized in Fig. 2. The exterior walls comprise of a wooden structure provided with rockwool in between and expanded polystyrene on the outside.

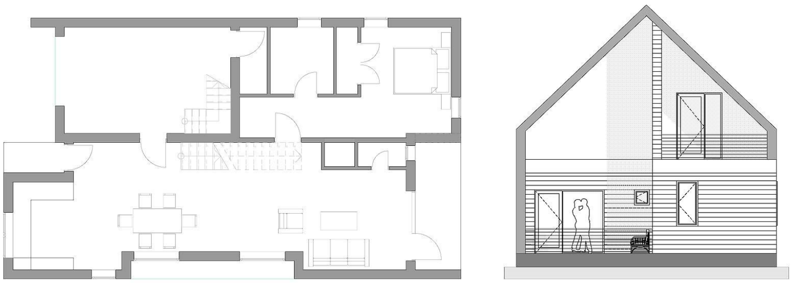

Fig. 2 – Schematized floor plan and facade for Building A.

Building B represents a dwelling with a ground floor, one upper level and a ventilated attic. The volume dwelling inscribes in a parallelepiped with a foot print of 10 m by 14 m with a level height of 3 m, as schematized in Fig. 3. The exterior walls are made of brick masonry with expanded polystyrene as thermal insulation.

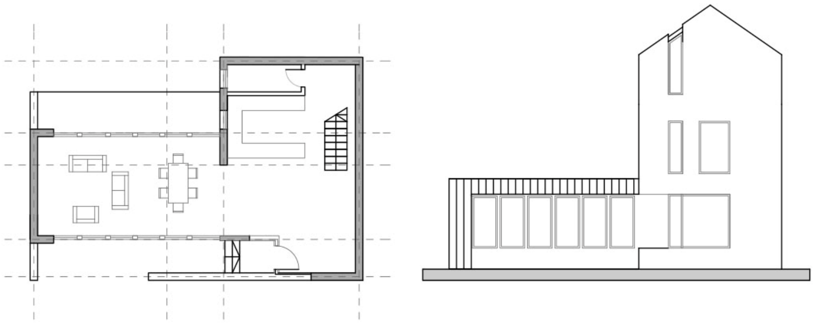

Fig. 3 – Schematized floor plan and section for building B.

The study follows the thermal-energy analysis for the two solutions using CASAnova software, in order to assess the energy performance evaluation. The program offers the possibility of compared analysis for multiple study cases with acceptable level of accuracy and reduced time for inserting the data and running the program. CASAnova software implies adopting an equivalent approximation for the buildings volume, specially for case study B which is formed by two different volumes with different vertical distribution: one is distributed only on ground level and the other on ground level, first level and ventilated attic. Thus, an approximation of the volume was conducted for building B, in order for the total volume to inscribe in a parallelepiped suitable for CASAnova data input.

Exterior climate conditions were chosen from CASAnova database for Budapest, Hundary, conditions similar to the climate of Romania.

Design parameters, geometric and thermal features for building A and B, respectively are presented in Table 2.

Table 2
Design Parameters, Geometric and Thermal Energy Features for Building A and B, Respectively

Building	Fraction of windows area at the façade %		U thermal transmittance coefficient W/m^2.K	Ventilation rate n, [1/h]	C thermal capacity kJ/K
A wood structure	N	12	0.76	0.60	1,900
	S	14	0.76		
	E	18	0.96		
	V	11	0.91		
	Roof		0.73		
	Lower floor		0.73		
B brick masonry	N	14	0.89	0.60	8,550
	S	16	0.83		
	E	15	0.89		
	V	19	0.81		
	Roof		0.89		
	Lower floor		0.97		

The two buildings analyzed differ in the percentage of glazing façade, insulation level of the roof and lower floor slab, but, especially by reflecting the thermal inertia characteristics. Thus, the time constant for the brick mansonry building, building A is superior to the wooden structure building B about 1.5 times and 1.5 times the thermal heat capacity.

Table 3

Simulation Results Regarding Annual Heating/Cooling Energy Demands for Building A and B, Respectively.

Building	Total specific energy demand W/m^2	Required specific energy for heating kWh/m^2	Required specific energy for cooling kWh/m^2	Number of heating degree hours Kh	Number of cooling degree hours Kh
A	150.3	135	15.3	4,838	1,834
B	238.7	227.8	10.9	5,444	1,634.5

Result simulations performed with CASAnova software, as shown in Table 3, highlights the significant influence of these parameters. Thus, in terms of heating demand, building A presents a higher level of energy efficiency, specific annual energy demand for heating representing 60% of the characteristics of building B with 88% for heating hours. In contrast, under summer conditions, building B has a better behavior, energy demand for cooling accounting for about 70% and the number of hours for cooling of 41% of those relating to building A.

Level of satisfaction regarding comfort requirements for summer conditions was analyzed on the basis of specific criteria concept of adaptive comfort and indoor temperature variations in relation to the outer two buildings under study, during the hottest month of the year, obtained by numerical simulation with the use of CASAnova software (Fig. 4).

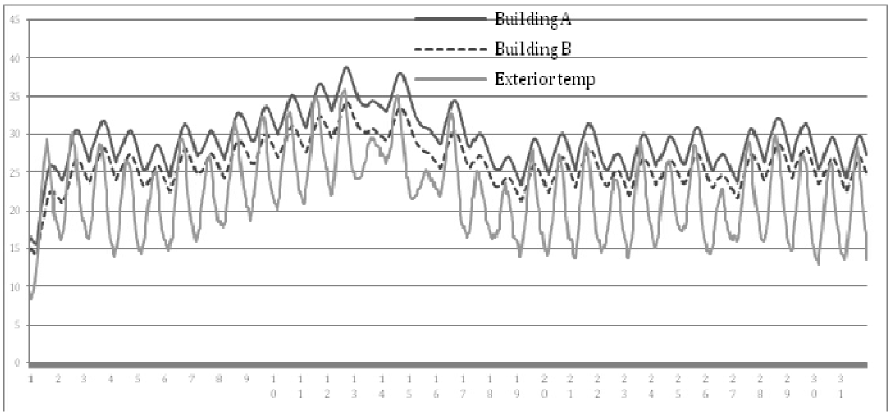

Fig. 4 – Indoor air temperature variation with respect to the outside air temperature for building A and B, respectively, for July.

The basic principle of the adaptive comfort concept was formulated as follows: *If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort* (Fergus & Humphreys, 2002).

Studies dealing with how comfort is perceived by users of a naturally ventilated space lead to the conclusion that comfort temperature is directly dependent and constant of the outside air temperature, varying within very wide limits. Thus, for an office building in Pakistan, the comfort temperature varies between 20°C and 30°C (Fergus & Humphreys, 2002).

The ideal temperature comfort, operative temperature θ_{op}, was calculated using eq. (1) proposed by de Dear and Brager, (2002):

$$\theta_{\text{op}} = 17.8 + 0.31\theta_e \,, \tag{1}$$

where: θ_e represents the outside air temperature.

This relationship was applied for minimum, average and maximum values for outdoor temperatures, specific for the months of July for Jassy area. Values obtained from this equation were compared with the actual indoor air temperature which resulted from numerical simulation. These air temperature values are presented in Table 4.

Table 4

Operative Temperature for Comfort in Relation to Indoor Air Temperature for Buildings A and B.

Parameters		Temperature values, [°C]		
		Min.	Med.	Max.
Outdoor air temperature		8.5	22.2	35.9
Operative temperature		20.4	24.8	28.9
Indoor air temperature (from simulations)	A	15.6	29.2	38.7
	B	14.2	26.2	34.4

The favorable influence of the thermal mass, reflective in thermal capacity C as shown in Table 2, is obvious. Temperature values for building A, wooden structure, are constantly exceeding outside temperature values, as opposed to building B for which the indoor air temperature values are lower than outside temperature values. Also, the actual values of indoor air temperature obtained through numerical simulation are closer to operative temperature values of comfort for building B with masonry structure.

It should be noted that given the pronounced differences between operative temperature values for comfort and actual values obtained from numerical simulation, on average 4.4°C for building A and 1.4°C for building B, emphasize the need for additional measures to increase the adaptability of the building to high outdoor temperature values and reduce the indoor air temperature value. For building B, the recommended solution is optimizing natural ventilation combined with the arrangement of green areas on the roof or façade. For the wooden building, A, the only probable solution to bring the indoor air temperature closer to the operative one is the use of air conditioning. A study in this sense is currently ongoing.

4. Conclusions

Impact of climate change on buildings manifests mostly by increased indoor air temperature values which during hot weather leads to values that not only exceed comfort levels but are responsible for mortality and morbidity rates.

Main possibilities regarding methods to increase buildings adaptability to climate change concern the general design of buildings, optimized ventilation, air conditioning systems and user behavior.

The analysis conducted on the two detached houses with similar thermal energy characteristics, building A and B, respectively, highlight the important role that thermal massiveness holds in ensuring comfort conditions under high outdoor temperature values and reducing energy demand for cooling. Thus, the wooden structure building is characterized by a higher level of thermal insulation but also by a low thermal massiveness and shows values of the indoor air temperature 4.4°C higher than operational temperature values, whilst the masonry structure building with a lower insulation level but higher thermal massiveness presents a difference of just 1.4°C.

REFERENCES

Bullen P.A., *Assesing Sustainable Adaptation of Existing Buildings to Climate Change - COBRA 2004.* The Internat. Constr. Res. Conf. of the Royal Inst. of Chartered Surveyors, LEED Metropolitan Unive., 2004.

de Dear R., Brager G.S., *Thermal Comfort in Naturally Ventilated Buildings: Revisions to ASHRAE Standard 55.* Energy and Build., **34**, *6*, 549-562 (2002).

Fergus J.N., Humphreys M., *Adaptive Thermal Comfort and Thermal Sustainable Standards for Buildings.* Energy and Build., **36**, *6*, 563-572 (2002).

Gavan G., *Worcester Climate Change Impact Study.* Technical report, September 2004.

Gupta R., Gregg M., *Preventing the Overheating of English Suburban Homes in a Warming Climate.* Build. Res. & Inform., **41**, *3*, 281-300 (2013).

Hacker J.N., Holmes J.M., *Thermal Comfort: Climate Change and the Environmental Design of Buildings in the United Kingdom.* Built Environ., **13**, 2007.

Steemers K., *Adaptability and Change: Passive Desing versus Climate Change.* Proc. of the Tyndall/ CIB Internat. Conf. on Climate Change and the Built Environ. UMIST, Manchester, 2002.

Steemers K., *Desing Buildings to Adapt to Climatic Change (Notes for the CISBAT Keynote presentation).* CISBAT 2005 Conf., Lausanne.

Steemers K., *PV in the City. A Desing and Implementation Guide*. Renewable Energy World, *6*(*4*) (2001).

* * * *Adaptation to Climate change in the context of Sustainable Development.* www.teriin.org/events/docs/adapt

* * * *CASAnova software*, version 3.3, free educational version.

* * * *Climate Change, Impacts and Vulnerability in Europe 2012.* An indicator-based report. European Environment Agengy.

* * * *Establishing Research Directionsi in Sustainble Building Design.* Tyndall Center for Climate Change Research, Project Overview, 2001–2002.

* * * *Regions 2020. An Assesment of Future Challenges for EU Region.* Commission of the European Communities, Commission staff working document, Brussels, 2008.

ADAPTABILITATEA CLĂDIRILOR LA MODIFICĂRILE CLIMATICE ŞI ASIGURAREA CONFORTULUI ÎN CONDIŢII DE VARĂ

(Rezumat)

Impactul modificărilor climatice se manifestă nu numai asupra sistemelor de mediu ci şi asupra sistemelor sociale şi a calităţii vieţii. Pentru eliminarea costurilor asociate efectelor negative ale schimbărilor climatice la nivel global şi european se dezvoltă politici care vizează atât stoparea cauzelor cât şi reducerea vulnerabilităţii prin creşterea capacităţii de adaptare a sistemelor la noile provocări.

În cadrul acestor politici, un loc important le este destinat clădirilor, având in vedere că supraîncălzirea spaţiilor în care oamenii locuiesc sau işi desfăşoară diferite activităţi, poate avea consecinţe defavorabile nu numai asupra confortului ci şi asupra sănătăţii ocupanţilor.

Măsurile pasive care contribuie la creşterea capacităţii de adaptare a clădirilor vizează masivitatea termică, optimizarea ventilării, sisteme pasive de răcire, utilizarea suprafeţelor înverzite şi, nu în ultimul rând, modificarea comportamentului utilizatorilor.

Se prezintă un studiu de caz pe două locuinţe unifamiliale, cu caracteristici geometrice şi energetice similare, dar diferite ca masivitate termică. Analiza, bazată pe principiile conceptului de confort adaptiv, evidenţiază faptul că masivitatea termică contribuie efectiv la creşterea capacităţii de adaptare a clădirii la modificări climatice.