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CORRELATIONS BETWEEN THERMAL AND ACOUSTIC PERFORMANCES IN RESIDENTIAL BUILDINGS IN THE SCOPE OF BUILDING REGULATIONS IN SERBIA [*]

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Abstract. *The current process of aligning the national legislation with that of the European Union, combined with the attempts to provide a comprehensive overview of regulations in accordance with the European framework related to particular aspects of design and construction of buildings, has contributed to the next step in the harmonization as mutual comparison and synchronization of diverse performances of buildings, such as thermal and acoustic. The two groups of properties of a building refer directly to relevant aspects of residential convenience and comfort, which is a particularly interesting housing issue. As residential comfort is a variable category affected by the systems of regulations and standards, this paper will present an account of how relevant regulatory requirements of today's Serbia have treated thermal and acoustic comfort and related building performances, that is, of the extent to which their comparative analysis is possible throughout different periods of construction*.

Key words: *residential comfort, thermal performance, acoustic performance, regulations, synchronization.*

1. INTRODUCTION

Residential comfort, a term that defines several aspects combined to provide comfortable living in a space, is an issue which has been considered by the corresponding legislature in Serbia since the mid-1960s. Prior to that, residential development in this region had been characterized by the necessity of mass production in construction whereas the quality of housing in terms of comfort was rather under-appreciated. However, the application of the recently adopted Regulations on energy efficiency in buildings [1] should

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bring about significant changes in the design and construction practice, ensuring adequate comfort in buildings – not exclusively residential – which is a prerequisite for achieving necessary energy efficiency.

It was upon the adoption of the Regulations, which was mostly compliant with the current European legislation in this area, primarily the Energy Performance of Buildings Directive (EPBD) [2], that the greatest progress was made towards defining the conditions concerning the thermal performance of buildings. Among other actions, the adoption of the Directive was preceded by a comprehensive study that concerned the circumstances and the mutual compatibility of regulations in thermal protection of buildings in many European countries, ENPER-TEBUC [3]. This helped to take a unified stance on the issue of thermal calculations which would apply to most of Europe. Currently, another European project, Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions, focuses on the protection from environmental noise in buildings. In response, a domestic research project, Integrating and harmonizing the sound insulation system in buildings from the aspect of sustainable architecture, has been launched which, among other issues, concentrates on the correlations between thermal and acoustic properties of buildings.

Comfort of a space, besides its functional, spatial and aesthetic characteristics, can be viewed in terms of warmth, sound, light, or air quality; in this respect, its aspects differ accordingly [4]. Each of these aspects is usually considered by a completely different set of regulations, i.e. rules of construction, which may not necessarily evolve together or follow each other in a concurrent pattern or rhythm. A varying level of development of certain sets of regulations can be observed particularly during various interventions on existing buildings when, as a consequence of the diversity between the former and the current building standards, harmonization with all current requirements is underway. In such situations, as the future direction for the development of relevant legislation, there is a demand to reconsider the potential integration of the whole set or particular aspects of comfort requirements, i.e. building performances thereof.

As this paper is aimed at reviewing the correlations between thermal and acoustic performances of residential buildings, the synchronization of which is coupled with the evolution of relevant regulations, the first step in the research will focus on the summary of the development of such regulations in our community.

2. A Summary of the Development of National Legislation Concerning Thermal and Acoustic Protection of Buildings

The first requirements considering heat and sound protection in residential housing in the region date back to 1967, when the Regulations on minimum technical requirements in housing construction came into effect [5]. It was an interim solution preceding the adoption of specific technical regulations on thermal and acoustic protection of buildings, and it contained very few provisions related to the corresponding building performances.

With respect to thermal protection, the 1967 Regulations stipulated the boundary values for the heat transfer coefficient in the perimeter walls, ceilings and flat roofs, where the values for walls included climatic factors and a categorization of corresponding climate zones. It also stated that the coefficient should be determined with reference to summer and winter heat accumulation, vapor diffusion, and air tightness of the construction and the sealing. However, no definition of the calculation methods was given. As regards sound protection of buildings, the value of 45dB was set as the minimum sound insulation measure for floors and walls between two adjacent apartments for the sound range of 500−1000Hz, noting that this could be achieved by "a roughly built concrete ceiling of 300kg/m^2 minimum weight, i.e., a solid brick wall of the same weight and rendered on both sides".

In 1970, separate sets of regulations were established respective to thermal and acoustic protection, which marked the beginning of a completely separate system of corresponding standards.

2.1. The development of standards in thermal protection of buildings

Current practices relating to the verification of thermal properties of a building and its parts supposes the inspection of several relevant parameters:

- The heat transfer coefficient;
- Vapor diffusion and related characteristics;
- Summer thermal stability of the constructions; and,
- Specific heat losses.

In addition, the nature and content of the most recent legislation containing elements of thermal protection, the Regulations on energy efficiency in buildings, show that by adopting the principle which takes into account the performance of the applied technical systems while calculating the overall energy balance of a building, it is possible to gain full insight into its total energy performance. Therefore, when considering the development of standards in thermal or heat protection of buildings, the emphasis will be placed primarily on whether the given parameters exist in the regulatory system of any of the relevant periods, as seen in Table 1.

Table 1 An overview of the evolution of the system for calculating thermal requirements with respect to relevant parameters

Field of application		The year of introduction						
		1967	1970	1980	1987	1990	1997/ 1998	2011
Thermal insulation (Umax)								
Water vapor diffusion		–	–					
Summer exploitation	amplitude attenuation factor of temperature fluctuations	–	–					
	temperature delay fluctuations	–	–			–		
Specific thermal losses	of the building	–	–	–				
	of characteristic rooms	–	–	–	–	–		
Overall energy performance								

It is logical to assume that the boundary values for the parameters have become more strictly regulated in time; however, this does not bear significant weight in the present paper and thus will not be commented in particular, especially since this problem has been previously analyzed in other papers [6].

The first normative document which referred exclusively to the issues of thermal protection of buildings and contained provisions and protective measures in significantly greater detail was adopted in 1970 as the Regulations on technical measures and provisions for thermal protection of buildings [7]. It still did not include all the contemporary requirements for adequate thermal comfort but rather focused on defining the relevant data for the calculation and verification of building insulation properties, i.e., the heat transfer coefficient. Besides, as an indication of the necessity to check the characteristics for water vapor diffusion, which is nowadays a mandatory element of thermal calculations, it noted that in principle, "the constructions and elements of buildings must be protected against moisture", including moisture diffusion.

A decade later, in 1980, significant changes in addressing the issue of heat protection were introduced in a system of standards. For the first time a comprehensive approach to thermal protection of buildings was offered along with the definition of both the necessary requirements and the relevant calculation methods. The application of the standards was mandatory, defining the following:

- Technical requirements for thermal protection in design and construction of buildings, established according to the choice of the heating method and limiting fenestration to 1/7 room floor area, with strict restrictions in case the glass surfaces were to exceed the permitted maximum, defined by the JUS U.J5.600 standard [8];
- Heat transfer coefficient calculation methods upon the classification according to the complexity of the constructions, defined by the JUS U.J5.510 standard [9];
- Water vapor diffusion calculation methods, defined by the JUS U.J5.520 standard [10] and,
- Summer thermal stability calculation methods for the external building constructions, defined by the JUS U.J5.530 [11].

The complexity of such a system of calculations contributed to the fact that the standards defined not only the basic climate parameters pertaining to winter conditions, but also the values of projected temperatures and relative humidity in the rooms, along with the requirements referring to water vapor diffusion/condensation relative to summer conditions.

The next significant modification in the approach to thermal calculations occurred in 1987, when certain standards were considerably revised and extended. The essence of the change can be described as this: unlike the previous calculation, in which verification of the compliance with the minimum heat insulation requirements in building constructions had been the only condition in terms of thermal protection of buildings, now its purpose was also to determine the limit to the overall specific heat loss in a building. This led to the revision of the previous versions of the standards, JUS U.J5.510 – Calculation methods for heat transfer coefficient in buildings and JUS U.J5.600 – Technical requirements for design and construction of buildings.

In this first revision of the standards, thus defined overall specific heat losses comprised specific transmission losses determined by shape factors and losses caused by natural or artificial ventilation of buildings. This approach required that the calculation methods of the heat transfer coefficient, defined by JUS U.J5.510, be more elaborately defined and customized to the newly established needs, which in turn induced a systematization of different types of construction element structures along with their potential interrelations and intersections. The revised requirements were considerably more closely defined with regard to various ventilated constructions, which were now categorized as: a) very poorly ventilated, b) poorly ventilated, and c) well-ventilated. The methods for calculating their thermal properties were also considered.

Another novelty related to technical requirements in design and construction lay in the different approach regarding the limits to the maximum fenestration area. This version of regulations did not stipulate general restrictions in terms of the area under glass surfaces of the façade; rather, it required additional heat protection measures in case of exceeding the boundary of 1/7 room floor area either by applying additional thermal protection, improving the insulation of the building, or using appropriate protective covering. The 1987 version of the standard calculations included a wider range of different factors which could be considered as climatic and were more accurately defined by detailed weather charts and external temperature estimates. In addition, cardinal direction also gained importance with respect to the mandatory use of glass surface protection against solar radiation.

In the following period, particular standards sporadically underwent mostly minor corrections. The JUS U.J5.600 was first amended in 1989, and the JUS U.J5.530 was first revised in 1990 and then in 1997, when the JUS U.J5.520, regulating water vapor diffusion, was also slightly improved. The most recent significant correction was introduced in 1998, bringing about profound changes to the JUS U.J5.600. On this occasion, the acceptable losses were allowed not only for the building as a whole but also for specific rooms within. The nature of other changes could be said to have been technical or merely superficial. It should be noted that at a certain point the relevant JUS standard versions were translated into the SRPS standard system without changes to the specific content.

Despite the increasing demands for further improvements in thermal protection regulations and their aligning to the European trends, they have yet to be materialized. This resulted in the fact that the recently adopted Regulations on energy efficiency of buildings incorporated all these elements and thus assumed, however temporarily, the position of the fundamental normative document in the thermal protection of buildings. Additionally, it has already been noted that the Regulations imposes the necessary verification of the overall energy performance of buildings, including considerations of both heat losses and heat gains, caused by either solar radiation or the appliances and installations within the building. In this respect, the nature and the concept of national regulations have approached the current European standards.

2.2. The development of standards in acoustic protection of buildings

In simple terms, the regulations prescribing the design and construction conditions pertaining to acoustics, i.e., sound protection, should define the following parameters:

- Minimum values of the sound insulation of a partition – airborne noise issues;
- Maximum values of the impact sound levels – structural noise issues; and,
- Maximum permissible noise levels in the rooms for living.

Accordingly, with respect to the development of sound protection standards, it will suffice for this paper to establish the existence of these parameters in the corresponding regulations in any relevant periods, as shown in Table 2.

The first legal provision to address the problem of sound protection of buildings was adopted in 1970 as the Regulations on technical measures and requirements for the sound protection of buildings [12]. This document made provisions for the acoustic protection in various types of buildings (residential, public, and commercial) and had effect in the design, construction, reconstruction and maintenance. It was structured as to include three characteristic segments: terms and definitions, minimum sound protection requirements, and verification of sound protection and sound transmission. Each segment was later developed into a different group of standards related to acoustics. Interestingly, although the document regulated sound protection, it did not regard noise or noise protection in any respect, which somewhat limited its adequate use in any types of buildings [13].

Table 2 An overview of the evolution of acoustic requirements with respect to relevant parameters

Field of application	The year of introduction			
	1967	1970	1982	1989
Airborne sound – min. sound insulation of the partition				
Impact sound – max. level of impact sound	-	-		
Noise – max. permissible level in living zones	-	-		

In the early 1980s, an elaborate system of standards in construction acoustics had already been established upon the previous developments of the related legislation, which is still relevant today. Among these, the JUS U.J6.201 standard – Technical requirements for design and construction of buildings [14], was the most significant for practical application by its definition of sound protection requirements for different types of buildings which were to be met in the procedures of design, construction or reconstruction. Adopted in 1982, the mandatory standard provisions stipulated the minimum values of sound insulation indices for the corresponding construction elements (walls, ceilings, windows, and doors) with reference to airborne (impact) sound, as well as the maximum values of sound transmission in the floor-ceiling constructions and joints for buildings of various purposes. Significantly, the regulations introduced a new classification scale for windows and doors according to their insulating power and prescribed the maximum permissible noise levels for the residential zones in housing facilities depending on time of day (30dBA at night and 40dBA during the day).

In 1989, this standard was revised so as to include updated and extended provisions. Besides the extension to relevant table of this standard, which defined the types of constructions as subject to standardization and stipulated their corresponding insulation capacities, other values were introduced in which the insulation power was expressed as R_w and L_w for airborne and structural noise, respectively. This differed from the previous version of the standard, in which it was expressed as the sound protection index. To an extent, the change made it more difficult to compare between the data done in different versions of the standard; however, there were no substantial alterations to the values or tightening of the criteria for insulation capacities of the partitions. The revised standard provided for a more accurate definition of permissible noise levels in day/night conditions for different purposes of buildings and rooms in them. In addition, it explicitly listed the requirements to be met by the façade elements of the building under inspection for insulation capacities with regard to the maximum permissible noise levels. It should be noted that the effective insulation power of the façade wall is checked mainly in relation to the window as the "acoustically weak" element of the façade wall structure with respect to its insulation power, as well as in relation to the logarithmic ratio of the window area and the façade wall area [14]. It is worth noticing that this version of the standard is still in effect although the former JUS nomenclature was changed into the SRPS standard.

3. Building Structure Properties in View of Thermal and Acoustic Requirements

Regulations on energy efficiency of buildings represent a current legislative act which, based on the principles of present European standards [15], defines the provisions for design and construction of buildings in an integrated and comprehensive manner, considers the necessity to meet all comfort requirements. Hence, it provides the concrete conditions related to thermal and acoustic comfort, a matter of primary interest of this paper, which should be concurrently satisfied. As for thermal comfort, these could be expressed as the need for:

a. correct dimensioning of the envelope elements;
b. protection against solar radiation;
c. providing thermal mass;
d. passive/natural nocturnal cooling;
e. thermal zoning of the building; and,
f. adequate shape of the building, and/or use of shades and drapes during the period of overheating to prevent the effects of direct solar radiation.

With respect to acoustic comfort, the Regulations stipulate that it be achieved by providing the following measures:

a. adequate airborne sound insulation of interior building elements (walls, ceilings, doors);
b. adequate airborne sound insulation of exterior building elements (façade walls, façade openings, roof coating);
c. adequate impact sound insulation of floors and partitions;
d. acceptable sound pressure levels in rooms, including any sound used to mask overhearing;
e. adequate acoustic response of the rooms or spaces in which audibility and quality of useful sounds are determined; and,
f. adequate design of installation systems, which must not violate the above measures.

Moreover, in order to ensure an integral view of the building with regard to thermal and acoustic requirements, it is necessary first to detect their common points, that is, the similarities and differences in the method by which the building and its components are observed. The obvious similarities and analogies between these two sets of requirements can be seen in the following:

1. In both cases, the characteristics of building structure components are observed relative to the outside-inside boundary, i.e. the properties of the external envelope, and to the interior of the building with respect to the characteristic thermal boundaries separating differently heated sections, or acoustic boundaries between spaces allocated to different users or purposes.
2. Both sets of requirements provide for differences in composite wall constructions: thermal specifications recognize different types of façade walls [9], and acoustic specifications recognize single, double, and multiple partitions as well as those with double or multiple layers [16, 17].

3. Both sets provide for the existence of the respective thermal and acoustic bridges as specific points in the building structure through which heat or sound is transmitted to a greater extent than is the case in the immediate environment.

In this paper, further analogies between heat and sound will not take into account the complexity of constructions affecting the methodology of corresponding calculations; the emphasis will rather be on the comprehension of various types of building structures that have existed in each of the analyzed set of regulations.

The issue of mutual compliance between the observed performances of residential buildings gains in importance during the reconstruction of existing facilities. Recent studies in the characteristics of the building stock in Belgrade and Serbia indicate that the majority of the existing residential buildings were built before 1970, that is, before the adoption of the first legislation on thermal and acoustic protection [18, 19]. Thus, the structure of such buildings inevitably must be upgraded and aligned to the current regulations. However, although the chronological development of the relevant thermal and acoustic legislation had been loosely parallel until the end of the 1980s, since then there have been amendments to particular standards exclusively in the domain of thermal protection, finalized in the recent changes within the Regulations on EE of buildings, whereas the most important current standard in sound protection which defines the technical requirements for design and construction of buildings dates back to that period. (Figure 1)

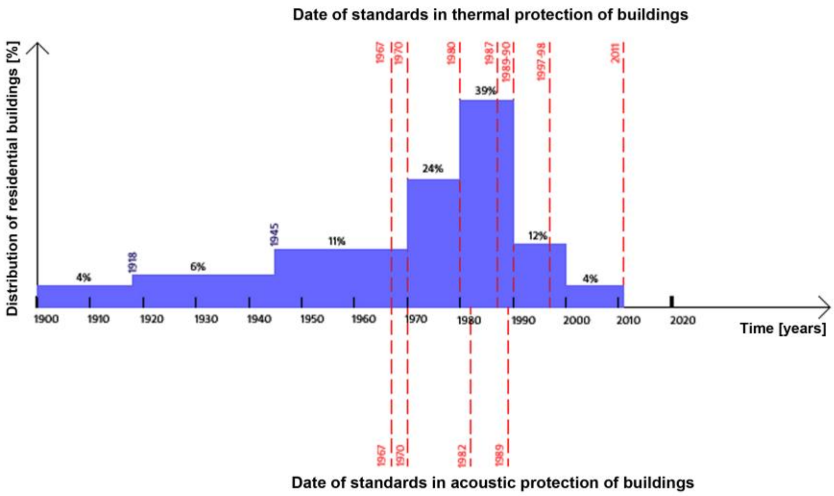

Fig. 1 Distribution of residential buildings in Serbia with respect to the relevant periods and the characteristic year of introduction of thermal and acoustic regulations

In future comprehensive studies of thermal and acoustic protection in the existing buildings, it will be of particular interest to review the scope of regulations which define conditions for design and construction with reference to heat (JUS/SRPS U.J5.600 and the Regulations on EE of buildings) and sound (JUS/SRPS U.J6.201) considering the types of building structures that were the subject of their separate interest at a given moment. The differences between the types may be expected primarily in the interior constructions as, until recently, they were included in thermal considerations only if they constituted the thermal envelope of the building; at the same time, the horizontal and vertical partitions between adjacent apartments were not always considered although they are very significant acoustically. (Table 3)

Table 3 A comparative overview of representative characteristic positions inside the building within the system of regulations on thermal and sound protection of buildings

Thermal	The year of introduction	1970	1980	1987	1998	2011
Thermal	No. of positions stipulated by the regulations	9	8	9	18	20
	Wall/Ceiling between 2 apartments				–	
Sound	No. of positions stipulated by the regulations	8	16	17		
Sound	The year of introduction	1970	1982	1989		

4. Final Considerations

It can be concluded from the above comparative review of the conditions and characteristics of national regulations on thermal and acoustic protection of buildings that the requirements in both sets have had largely similar development. However, despite a certain lag in practical applications, thermal standards have been amended more recently and are better harmonized to European regulations, which is a feat yet to be accomplished in acoustic standards.

Moreover, standards have been used to amend and mainly extend the lists of building structures with properties to be inspected and aligned with corresponding requirements; yet such changes have not always been fully synchronized due to either the nature of the issue or the change in attitudes in a particular period of time. Thus, there are certain positions in the buildings dating from the periods of such inconsistencies that may require corresponding interventions during refurbishment. It is certain that various improvements to the existing building structures will occur simply because of the stricter criteria, which is not insignificant considering the fact that the highest percentage of the existing housing had been built by 1970. It remains to be seen how such integrations will perform in future practice.

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KORELACIJA TERMIČKIH I AKUSTIČKIH PERFORMANSI KOD STAMBENIH OBJEKATA U OKVIRIMA GRAĐEVINSKIH PROPISA U SRBIJI

Aktuelni proces usklađivanja domaće sa evropskom regulativom sa jedne strane, kao i nastojanje da se u evropskim okvirima sagledaju i harmonizuju propisi iz pojedinačnih oblasti koje se tiču aspekata projektovanja i građenja objekata, doprineli su da se kao sledeći korak harmonizacije nametne međusobno upoređivanje i sinhronizovanje međusobno različitih performansi zgrada, kao što su npr. termičke i akustičke. Ove dve grupe svojstava neke zgrade su direktno vezane za odgovarajuće aspekte udobnosti, odnosno komfora boravka, što je kao problem posebno zanimljivo kada je reč o stambenim objektima. Kako uslovi komfora predstavljaju promenljivu kategoriju koja može biti uslovljena sistemima propisa i standarda, ovim radom će biti prikazano kako su tokom vremena u relevantnoj regulativi današnje Srbije tretirani uslovi toplotnog i zvučnog komfora i iz njih izvedene performanse objekata, odnosno, u kojoj meri se one mogu uporedo pratiti u različitim periodima građenja.

Ključne reči: *komfor stanovanja, termičke performanse, akustičke performanse, regulativa, sinhronizacija.*