THE EFFECT OF DENSITY ON IMPACT SOUND INSULATION OF THE EXPANDED POLYSTRENE (EPS) BLOCK USED AS FILLER IN ONE WAY HOLLOW CORE SLAB IN DWELLINGS

A Master's Thesis

By

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September 2016

To my chance and biggest supporter of my life , Pelin Biçer

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ANKARA
September 2016

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.

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ABSTRACT

THE EFFECT OF DENSITY ON IMPACT SOUND INSULATION OF THE EXPANDED POLYSTRENE (EPS) BLOCK USED AS FILLER IN ONE WAY HOLLOW CORE SLAB IN DWELLINGS

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The current international standards and governmental regulations stipulate maximum impact sound insulation on construction slabs of buildings to increase acoustical comfort of interiors of dwellings as mentioned by Cost Action TU 0901:2014 study. In Turkey, the most common slab construction is one way hollow core slab with EPS filler. However, according to the feedback given by users who live in multi storey dwellings impact sound insulation of expanded polystyrene used construction slabs of dwellings is more than acceptable values. In the literature, there is not any information about impact sound insulation performance of one way hollow core slab with EPS filler and the effects of EPS density differences on impact sound so a comparative study on impact sound insulation of the one-way hollow core slab with EPS filler was conducted. The study aimed to determine what is impact sound insulation performance of expanded polystyrene fillers in one way hollow core slab system and the effect of density difference of EPS fillers in one way hollow core systems used in dwellings. The study has also highlighted the importance of missing impact sound isolation standards and regulations in Turkey. The research was based on TS EN ISO 10140-3:2011 laboratory measurement of impact sound insulation of building elements and the data collected was analyzed according to TS EN ISO 717-2:2013. A sample one way hollow core slab system which is used in real life constructions was designed and built with 16 kg/m^3 and 10 kg/ m^3 EPS fillers. The results showed that one way hollow core slab with EPS fillers demonstrate very low impact sound insulation performance when compared with recommended values, standards and regulations accepted by many European countries. In addition, it was observed that the impact sound insulation performance of 10 kg/m^3 expanded polystyrene filler in one way hollow core slab was better than the performance of 16 kg/ m^3 EPS filler.

KEYWORDS: Acoustical Comfort, Expanded Polystyrene, Impact Sound, Isolation between Flats, One-way Hollow Core Slab,

ÖZET

GENLEŞTİRİLMİŞ POLİSTİREN (EPS) BLOK DOLGU KULLANILAN TEK YÖNLÜ ASMOLEN KONUT DÖŞEMELERİNDE YOĞUNLUK FARKININ DARBE SESİ YALITIMINA ETKİSİ

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Cost Action TU 0901:2014 çalışmasında değinildiği gibi, güncel uluslararası standartlar ve ilgili yönetmelikler, binaların inşaat döşemelerinde maksimum darbe yalıtımını konutlarda iç mekân akustik konforunu arttırmak için şart koşmaktadır. Türkiye'de en yaygın döşeme tipi EPS dolgulu tek yönlü boşluklu asmolen döşemedir. Fakat çok katlı konutlarda yaşayan kullanıcıların geri dönüşlerine bakıldığında döşemelerde kullanılan genleştirilmiş polistirenin darbe sesi yalıtımı kabul edilebilir değerlerin altındadır. Literatürde, EPS dolgulu tek yönlü boşluklu asmolen döşemenin darbe ses yalıtımı verimliliği ve darbe sesi üzerindeki EPS yoğunluk farkının etkisi hakkında bilgi bulunmuyor bu sebeple EPS dolgulu tek yönlü boşluklu asmolen döşemenin darbe ses yalıtımı üzerinde kıyaslamalı çalışma ortaya konmuştur. Bu çalışma, genleştirilmiş polistiren dolgulu tek yönlü asmolen döşeme sisteminin darbe sesi yalıtım performansını ve tek yönlü asmolen döşeme içindeki EPS dolguların yoğunluk farkının darbe sesi yalıtımına etkisini belirlemeyi hedeflemiştir. Çalışma aynı zamanda Türkiye'de darbe sesi yalıtımı standartlarının eksikliğini ve önemini vurgulamıştır. Bu araştırma TS EN ISO 10140-3,2011 yapı elemanlarının darbe sesi yalıtımının laboratuvar ortamında ölçümlerine ve elde edilen bilginin TS EN ISO 717-2,2013'e göre analiz edilmesine temellendirilmiştir. Gerçek yapılarda kullanılan tek yönlü EPS asmolen döşeme örneği tasarlandı ve 16 kg/m3 ve 10 kg/ m3 EPS dolgular ile inşa edildi. Sonuçlar EPS dolgulu tek yönlü asmolen döşemenin birçok Avrupa ülkesi tarafından kabul edilen ve tavsiye edilen değerler, standartlar ve düzenlemelere kıyasla daha düşük darbe sesi yalıtım performansına sahip olduğunu gösterdi. Buna ek olarak, tek yönlü asmolen döşemede genleştirilmiş polistirenin 10 kg/m3 darbe ses yalıtım performansının 16 kg/ m3 EPS dolgudan daha iyi olduğu gözlendi.

ANAHTAR KELİMELER: Akustik konfor, darbe sesi yalıtımı, genleştirilmiş polistiren, katlar arası yalıtım, tek yönlü asmolen döşeme

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ABBREVIATIONS

ABBREVIATION	EXPLANATION
EPS	Expanded Polystyrene
EUMEPS	European Manufacturers of Expanded Polystyrene
EPSDER	Expanded Polystyrene Industry Association
TS	Turkish Standard
EN	European Standard
ISO	International Organization for Standardization
EPS 10	The slab name designed with $10kg/m^3$ EPS block filler for the tests
EPS 16	The slab name designed with $10kg/m^3$ EPS block filler for the tests

CHAPTER I

INTRODUCTION

In recent years, fast growth of urban population has led to linear rise of dwellings due to high cost of building plots and construction investments in Turkey. The multi-storey (10-20 storey) buildings can be constructed rapidly, easily and intensively thanks to both material and construction techniques by modernized and improved construction market. In this context, sound transmission between spaces and acoustical comfort of interiors is gaining importance in adjoining multi-storey dwellings each passing day. The acoustical comfort level of the interiors change according to preferred construction material's technical specifications. As Egan (2007) puts forward impact sound energy can demonstrate downward reflection on construction slabs easily. Therefore, whole constructional members of a building system should be isolated from impact sound energy as much as possible. Thus, the slabs of the adjoining multi-storey systems gain importance to omit impact sound transmission between architectural spaces.

As indicated in the study titled “Building Acoustics throughout Europe Vol.1 by Cost Action TU0901, general noise exposure due to sound transmission in attached housing systems may have an impact on the householder's health and wellbeing (Cost, 2014). In addition, noise or sound that is unavoidable, unnecessary or emotive is often the most annoying because activities like sleeping, reading, studying and listening television/radio are the common noise-disrupted activities (Cost, 2014). The effect of sound on health can depend on an individual's sensitivity, health profile, circumstance and perception or control over the noise problem (Cost, 2014). The intrusion of noise into a home can affect occupant's life in different aspects. For example, householders' perception of noise and their reaction to the received sound can influence relationship that already exists with their neighbours (Cost, 2014). Therefore, as stated by Egan, impact sound emerges easily and erratic just by walking or dropping an object so to enhance acoustical comfort of interiors about impact sound insulation seems to be of utmost importance (2007).

Cost Action TU0901 stated that Turkey does not have any governmental regulations or technical standards to maximize neither acoustical comfort of interiors nor impact sound insulation (Cost, 2014). However, the same study demonstrates that there are many different regulations and standards available to maximize acoustical comfort and also impact sound insulation performance of dwellings in European countries with different descriptors. In Europe, governmental regulations are based on ISO 717-2. For instance, Germany, Austria, Lithuania and Denmark demanded received impact sound pressure level ($L_{n,w}$) when highest value should be $\leq$ 53 dB (Cost, 2014).

One-way hollow core slab systems have been utilized commonly in multi-storey dwelling projects in recent years by enhanced construction technologies to get wider spans and to minimize beam heights. The expanded polystyrene is evaluated as construction material, beyond being a thermal insulation material. It is a kind of filler material in one-way hollow core slabs to diminish dead load of the slab. Low cost and widespread production of the EPS make it competitive for one-way hollow core slab constructions. The conducted researches show us that expanded polystyrene analysed as thermal insulation material and it is subjected to different thermal and characteristic performance evaluations. In addition, there are limited studies available about acoustical performance of the expanded polystyrene, however, there is any study available about EPS block gap fillers in one-way hollow core slab systems. When user feedback is analysed, it can be concluded that impact sound insulation performance of expanded polystyrene block filler used in one way hollow core slabs of multi-storey dwellings is weaker than other slab systems because of received high level of impact sound level in interiors during daily life. The impact sound insulation of a construction slab is alteration of sound isolation value according to mass law and stiffness of construction slab layers. In addition, selection of flexible construction slab supportive elements between layers helps to increase impact sound insulation value (Egan, 2007). Therefore, the purpose of this study is to determine impact sound insulation of expanded polystyrene slab filler blocks used one-way hollow core slabs preferred in multi-storey dwellings and also determine the effects of density differences of the EPS block fillers in the slab system to see the performance of the slab without any supportive layers to increase impact sound insulation. The conducted laboratory tests in the light of TS EN ISO 10140-3:2011 performed on prepared two different density EPS filler preferred one way hollow core slab system and then, received data analysed according to TS EN ISO 717-2:2013. Thus, the impact sound insulation performance of one-way hollow core slab system with EPS fillers and effects of density differences of the EPS fillers are specified and a significant study conducted to attract attention of acoustical comfort of dwellings in Turkey from impact sound insulation aspect.

1.1. Aim and Scope

This thesis focuses on impact sound insulation performance of one way hollow core slab systems with EPS block filler, in addition, determine effects of EPS filler density differences on impact sound insulation performance while using in a one-way hollow core slab. As for the method in this study, a one-way hollow core block slab system was prepared with the EPS block fillers which has the same thickness and sections but different densities. One of the slab systems contains 16 kg/m^3 density, 25 cm thickness solid block EPS as a filler in hollow core slab system (EPS16), the other one contains 10 kg/m^3 density, 25 cm thickness solid block EPS as a filler in hollow core slab system (EPS10). EPS10 was selected because only 10 kg/m^3 density is commonly used in the construction market in Turkey. Preferred EPS filler blocks in hollow core slab system does not have a density of more than 10 kg/m^3 in the slab systems because of limited budgets and investment of the contractors. EPS10 is technically accepted minimum value for civil engineering applications because lower density is weak against concrete load. On the other hand, Yucel, Basyigit and Ozel (2003) mention that 15 kg /m^3 is the minimum density according to DIN 53420 standard for construction In Turkey, closest available mass production value to DIN53420 is 16 kg/$m^{3.}$ Thus, the slab was designed with 16 kg/m^3. Moreover, 15-16 kg/m^3 is the minimum value for EPS density for construction market in Europe; however, in Turkey producers keep production sometimes lower than 10 kg/m^3 for construction market although it has weak performance against construction system pressure and thermal insulation.

The missing standards and governmental regulations of acoustical comfort of interiors in Turkey, performance of the one way hollow core slab system has not been tested before against especially impact sound. The measurement of impact sound insulation performance of the slabs test performed on the prepared slabs in the Turkish Standard Institute (TSE) Tuzla Acoustic Laboratory in Istanbul, Turkey to get results from big scale test sample. The performed tests gave the chance to determine the performance of the slab and compare the effects of density differences on impact sound insulation. In scope of this study, impact sound pressure levels (L_1) of prepared slabs was measured and reported in receiver room at 1/3 octave band. At the end, according to related values of 1/3 octave band, impact sound insulation of the hollow core slabs with EPS block filler and comparison of the two different density of EPS block filler were determined.

Besides, this study aims to highlight the issue of missing acoustical comfort standards and regulations, and attract attention to increase and modify production and usage quality of EPS as a construction material. This study paves the way for new studies about acoustical performance of EPS as a construction material like performance analysis against airborne sound on slab or between rooms, or performance of analysis of hollow core slab systems with different fillers.

1.2. Structure of the Thesis

The thesis is composed of four main chapters. The first chapter is the introduction. This chapter sets the study in context and gives brief information about the purpose of the study and its significance. Furthermore, the introduction identifies the overall methodology of the study, literature review, and case study, as well as the research techniques employed in the case study. The introduction concludes by outlining the structure of the thesis.

The second chapter titled “Sound Transmission in the Building Elements” is divided into four main subtopics. Firstly, literature review into impact sound, rating method of impact sound, solutions to keep structure from the impact sound energy have been mentioned. Secondly, standards have been investigated in detail to see steps of the performed tests in the laboratory in the light of TS EN 10140-3:2011. Then, the EPS as a construction material has been studied to understand what kind of a construction material it is, advantages, disadvantages and characteristics of it have been analyzed . In the fourth part, studies about impacts sound insulation and expanded polystyrene have been studied.

In the third chapter, design of the study and research question and hypothesis have been explained, then, methodology and context of the study has been clarified. At this point, the performed laboratory tests according to TS EN ISO 10140-3: 2011, Acoustics – Laboratory Measurement of Sound Insulation of Building Elements – Part 3: Measurement of Impact Sound Insulation standard is explained in detail. Moreover, this section explains the construction of sample slabs in detail with used materials and selected expanded polystyrene fillers. Then, the section focuses on techniques of the TS EN ISO 10140-3: 2011 during the measurement period of impact sound isolation performance of the slabs.

In the fourth chapter, findings of EPS10 and EPS16 from the performed tests in 1/3 octave band have been presented and the collected data has been analyzed in the light of the standards and findings of the former studies. The comparison of density difference is completed at the end of this section to see performance of the EPS block fillers.

In the conclusion part, the study is concluded with the major results of the study. In addition, in this section, contributions of the study, limitations which were encountered during study, and suggestions for further research is discussed.

CHAPTER II

SOUND TRANSMISSION IN THE BUILDING ELEMENTS

2.1. Sound Transmission Through Building Elements

Sound is defined as ‘the response of human ear to pressure fluctuations in the air caused by vibrating objects’ (Metha, Johnson & Rocafort, 1999). The sound is defined also as a physical disturbance in a medium that is capable of being detected by the ear or hearing sensation excited by a physical disturbance in the medium (Harris, 1994). The pressure variations are originated in several ways like, vibration of a surface like building slab, repetitive pulsations in an airstream such as produced by rotating fan blades, through vortices which result when an airstream strikes an obstruction and by the impact of one mass with another (Harris, 1994). Sound is transmitted in buildings easily because noise usually is communicated to rooms within a building via many different ways, from noise sources elsewhere in the building (Harris, 1994). Therefore, to create quiet atmosphere in building spaces needs to take precautions for noise control which is the technology of obtaining an acceptable noise environment consistent with economic and operational considerations (Harris, 1994).

Buildings support different activities like speech, music, studying, work or rest and sleep, all of these activities adversely affect each other by noise or vibration of structural elements. Noise from outside of the building also affect the activities inside of the building. Harris highlights that people are usually annoyed and distracted by noise (Harris, 1994). In addition to this, noise is considered as a public nuisance (Harris, 1994). Social surveys in several European countries demonstrate that multi-storey housing occupants complained and were annoyed by the noise caused by neighbor's activities (Cost Action TU 0901, 2014). Noise control which is the technology of obtaining an acceptable noise environment consistent with economic and operational considerations is necessary to create quiet atmosphere in building spaces and considerable efforts need to be made to control to noise (Harris, 1994). Noise is transmitted in buildings easily because noise usually is communicated to rooms within a building via many different ways, from noise sources elsewhere in the building or from noise source to outside of the building (Harris, 1994). To decrease sound transmission of the systems because even small holes, open seams or any kind of gaps and cracks can significantly reduce sound isolation, these kind of possible sound moving ways should be controlled and closed (Egan, 2000).

2.1.1. Impact Sound Insulation

The sound is transmitted in buildings in different ways such as airborne sound transmission and impact sound transmission. The impact sound is a kind of sound which originated as impact communicated with the building structure (Harris, 1994). Vibration or impact causing object that is rigidly attached to a building element will cause the element to vibrate (Metha, Johnson & Rocafort, 1999). Impact is a result of a force that occurs for a short duration so it can be repetitive but it is not periodic in nature in general; however, vibration is periodic and continuous (Metha, Johnson & Rocafort, 1999). The impact noise is erratic and it emerges easily while walking, rolling carts, dropping objects, shuffling furniture, slamming doors and the like (Egan, 2007). The level of the received impact sound pressure varies according to the type of sound source on a floor and hardness of the surface layers of buildings (Harris, 1994).

Impact sound energy is communicated in a building structure and it can easily spread to other locations in the building and vibrate the surfaces by radiated noise (Harris, 1994). Then, the impact sound is received by the listeners as airborne sound radiated from vibrated surfaces like walls or ceiling (Harris, 1994). There are many paths available in buildings for moving of impact sound (see Figure 1). The impact sound energy can spread about 35 m far from the source (Harris, 1994).

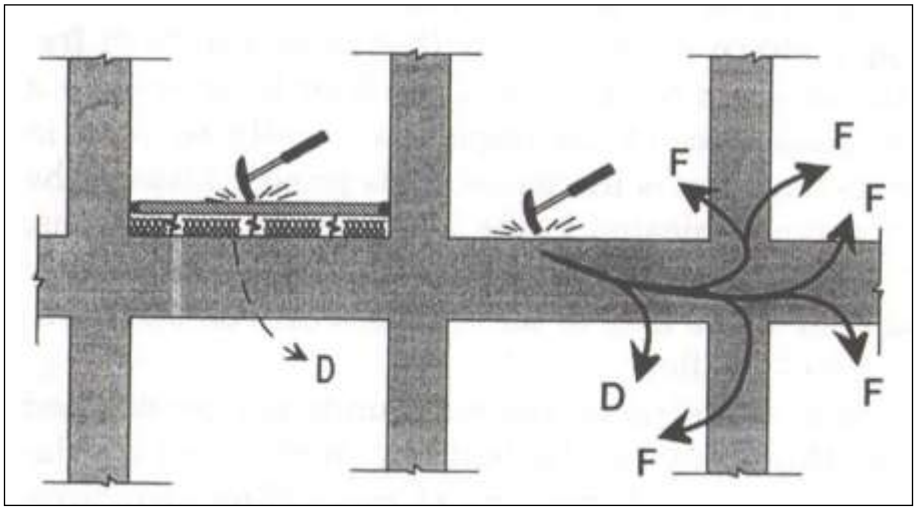

Figure 1. Paths for impact sound in a concrete building (Harris, 1994.) The letter D in the figure demonstrate the impact sound energy radiate through direct way, and the letter F demonstrate the transmitted impact sound by flanking paths.

2.1.2. Rating Impact Sound Transmission

"Impact Insulation Class" (IIC) is a single number rating for rating impact sound insulation (Harris, 1994). IIC measure is a measurement of the impact sound insulation level provided by construction system (Harris, 1994). The higher results of the impact sound insulation class rating demonstrate better impact noise insulation by the construction system (Harris, 1994). Impact sound insulation is enhanced by increasing the mass of the floor layers like joist or truss construction (Harris, 1994). The mass of the structure and its damping affects the impact sound energy dissipation in a building structure. Thus, a lightweight structure which has low damping radiates more noise than a massive building structure (Harris, 1994). For example, concrete floors generate around 10 dB less at low frequencies than lighter joist or truss systems performed, so massive constructions are preferred more (Harris, 1994).

In Europe, there are significant differences among countries when sound insulation in descriptors and requirements for dwellings are concerned. According to the results of the Cost Action TU 0901 study, there are several descriptors available for impact sound insulation requirements (2014). Table 1 indicates how many countries apply different descriptors and also variants, recommendations and special rules about impact sound insulation. The standard EN ISO 717 series has been referred to and used since 1996 by allowing different descriptors and by introducing spectrum adaptation terms according to different extended frequency ranges (Cost Action TU 0901, 2014).

The main requirements for impact sound insulation is presented in Table 2. To reach reliable comparison of the requirements, all requirements were converted into estimated equivalent values for impact sound insulation based on room and construction types. Getting an exact conversion of countries is not possible because the values are estimates and there are significant differences especially between impact sound insulation requirements with max differences of equivalent L'_{nTw} limits more than 15 dB for multi-storey buildings (Cost Action TU 0901, 2014). According to Table 2, requirements in Turkey have been mentioned as ‘N/A’ as it is in preparation and, impact sound insulation requirements are not mandatory in Luxembourg, Macedonia, Malta, Turkey and Cyprus.

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Table 1. Sound insulation descriptors applied for regulatory requirements in 30 countries Europe in June 2013 (Cost Action TU 0901, 2014).

IMPACT SOUND	
Number of countries	**Descriptor**
18	L'_{nw}
1	$L'_{nw} + C_{1,50\text{-}2500}$
8	$L'_{nT,w}$
2	$L'_{nT,w} + C_1$
1	L'_w
?	Variants
?	Recommendations
?	Special rules

Table 2. Impact sound insulation between dwellings – Main requirements in 35 European countries (Cost Action TU 0901, 2014).

Main Requirements of 35 Countries			
Status June 2013		**Multi-storey building**	**Row housing**
Country	**Descriptor**	**Requirement (dB)**	**Requirement (dB)**
Austria	$L'_{nT,w}$	≤ 48	≤ 43
Belgium	$L'_{nT,w}$	≤ 58	≤ 50
Bulgaria	$L'_{n,w}$	≤ 53	≤ 53
Croatia	L'_{w}	≤ 68	≤ 68
Cyprus	N/A	N/A	N/A
Czech Republic	$L'_{n,w}$	≤ 55	≤ 48
Denmark	$L'_{n,w}$	≤ 53	≤ 53
England and Wales	$L'_{nT,w}$	≤ 62	NONE
Estonia	$L'_{n,w}$	≤ 53	≤ 53
Finland	$L'_{n,w}$	≤ 53	≤ 53
France	$L'_{nT,w}$	≤ 58	≤58
Germany	$L'_{n,w}$	≤ 53	≤ 48
Greece	$L'_{n,w}$	≤ 60	≤ 60
Hungary	$L'_{n,w}$	≤ 55	≤ 45
Iceland	$L'_{n,w}$	≤ 53	≤ 53
Ireland	$L'_{nT,w}$	≤ 62	NONE
Italy	$L'_{n,w}$	≤ 63	≤ 63
Latvia	$L'_{n,w}$	≤ 54	≤ 54
Lithuania	$L'_{n,w}$	≤ 53	≤ 53
Luxembourg	N/A	N/A	N/A
Macedonia	N/A	N/A	N/A
Malta	N/A	N/A	N/A
Netherlands	$L'_{nT,w} + C_1$	≤ 54	≤ 54
Norway	$L'_{n,w}$	≤ 53	≤ 53
			(cont.d)

Poland	$L'_{n,w}$	≤ 58	≤53
Portugal	$L'_{nT,w}$	≤ 60	≤ 60
Romania	$L'_{n,w}$	≤ 59	≤ 59
Scotland	$L'_{nT,w}$	≤ 56	NONE
Serbia	$L'_{n,w}$	≤ 68	≤ 68
Slovakia	$L'_{n,w}$ or $L'_{nT,w}$	≤ 55	≤ 48
Slovenia	$L'_{n,w}$	≤ 58	≤ 58
Spain	$L'_{nT,w}$	≤ 65	≤ 65
Sweden	$L'_{n,w} + C_{1,-2500}$	≤ 56	≤ 56
Switzerland	$L'_{nT,w} + C_1$	≤ 53	≤ 50
Turkey	N/A	N/A	N/A

2.1.3. Methods of Controlling Impact Sound

Impact sound is a kind of mechanical energy and it occurs directly from a building structure and its elements (Harris, 1994). To increase and control sound insulation in buildings, first of all airborne sounds and impact sounds could be distinguished. Most sounds in buildings are airborne sounds like human conversation, musical instruments and fans. Airborne sound transmission originates in the air (Harris, 1994). In buildings, from the source of sound, through the air to a partition which is forced into vibration by the sound waves; the vibrating partition acts as a new source of sound on the other side of the partition because sound waves in air change depending on atmospheric pressure; therefore; the force causes the movement of partition and generates sound in the adjacent rooms (Harris, 1994).

There are a number of usual complaints about the types of noise people can hear from the adjoining dwelling systems and to understand whether the sound is airborne, impact or both, Table 3 provides a summary of the types of sounds from adjoining dwellings and frequency range of sound is also involved. The Cost Action TU 0901 (2014) accepts frequencies between 40-200 Hz as low frequencies, frequencies between 250-1000 Hz as mid frequencies and frequencies between 1250-3000 Hz as high frequencies and “all” demonstrate a wide range of frequencies.

Table 3. Potential sound sources in housing, associated airborne or impact sources and typical frequency ranges involved (Cost Action TU 0901, 2014).

Potential Sound Sources in Attached Dwellings			
Sound Source Type	**Airborne Sound**	**Impact Sound**	**Sound Frequencies Influenced**
Teenagers or adult voices	X		mid-high
TV	X		mid-high
Door closing		X	low-mid
Radio/Music	X		all
Domestic equipment	X	X	all
Plugs being inserted into socket		X	low-mid
Switches being turned on or off		X	mid
Cupboard door closing		X	low-mid
Services noise (e.g. downpipes, vater pumps)	X		all
Footsteps		X	low-mid
Children playing	X	X	all
D.I.Y	X	X	all
Dogs barking	X		low-mid

Entire building structure should be prevented from impact sound energy because impact on floors is radiated directly downward (Egan, 2007). Egan (2000) states that while wall, floor and ceiling system are constructed, an airspace should be created between their layers and also using a kind of sound absorbing material should be used as a layer to dissipate sound energy within the cavity so, sound transmission value decreases. Airborne sound insulation is needed for all barriers on walls, floors and ceiling assemblies (Metha, Johnson, Rocafort, 1999). However, impact sound insulation primarily requires precautions on floors because most impact production rests on floors (Metha, Johnson, Rocafort, 1999).

The impact sound can be controlled at three steps; at source, on transmission path and at perception point (Harris, 1994). To control impact sound transmission, there are several techniques available. Firstly, the location of impact sound source need to be changed and located far from the low noise levels. For example, bedrooms must be far from high level impact noise available spaces such as kitchens or garbage chutes (Harris, 1994). Providing vibration isolation and decreasing vibration of the source provide more impact noise insulation, for example standing of washing machine on soft rubber pads (Harris, 1994). Moreover, strengthening the building structure at the points where vibration is high and keeping light weight structural elements like columns far from impact noise producers would be effective to decrease impact sound (Harris, 1994). As mentioned above, floors are main transmission points of the impact sound so to increase the impact sound insulation, covering the floor top surface with a resilient layer like a carpet, or getting high impact sound insulation creating floating floor construction with a resilient layer can be efficient especially at high frequencies (Harris, 1994). Besides, preferring suspended ceilings to minimize communication between floor construction above it and fulfillment of suspended ceilings gap between floor constructions with a resilient materials is another useful method (Harris, 1994). Finally, controlling all breaks and cracks to prevent sound transmission is important for controlling impact sound energy (Harris, 1994).

Impact sound transmission through walls occurs less than slabs but when impact sound occurs on them, it can be controlled by taking several precautions. Avoiding mounting the devices, pipes and similar sources, avoiding fixing kitchen or bathroom cabinets directly to walls without any resilient layer and installation of resilient pads on doors of cabinets can help to reduce impact sound transmission (Harris, 1994). In addition, wall panels like gypsum boards and plywood when constructed with resilient layer covered metal channels provide better insulation (Harris, 1994). Performance of the resiliently supported wall panel construction is enhanced by increasing the depth of the airspace, reducing of the supports' stiffness, increasing mass per unit area of the panel and fulfillment of sound absorptive material in the airspace between panels and the walls (Harris, 1994).

Another effective method for controlling impact noise transmission is making use of structural discontinues. Creating a gap in the building structure and expansion joints can be used to isolate noisy and quiet areas like separating performing and rehearsal areas from the mechanical room and any other noisy spaces in theater buildings (Harris, 1994)

2.2. Standards

According to the study of Cost Action TU 0901, sound insulation requirements for dwellings exist in many European countries, in addition several of them also have classification schemes (2014). The comparative studies about regulatory sound insulation requirements and sound classification schemes in Europe demonstrate that Europe demand a high degree of diversity about this topic (Cost Action TU 0901, 2014). The building acoustic requirements for dwellings have been existing for more than 30 years in many European countries and sound insulation requirements are supported by descriptors defined in standards (Cost Action TU 0901, 2014). The ISO standards are implemented as European (EN) standards and then Turkish standards (TS). ISO 717 series standards are used as international descriptors for evaluation of airborne and impact sound insulation (Cost Action TU 0901, 2014). There is a lot of data and governmental regulations available according to ISO 717-2 so this is the standard accepted as a way to evaluate impact sound insulation. In addition, this study is based on TS EN ISO 717-2 and has made it easy to compare the results with available data and will hopefully work as a basis to set regulations according to TS EN ISO 717 series in Turkey.

The aim of TS EN ISO 717-2: 2013 – Acoustics. Rating of sound insulation in buildings and of building elements – Part 2: Impact sound insulation is reaching single number quantities and the spectrum adaptation terms are derived from values measured according to TS EN ISO 10140-3: 2011 tests. TS EN ISO 10140-3: 2011 is based on Norsonic Nor277 tapping machine impacts which occur while a person who wears shoes walks, and the standards of the tapping machine must be compatible with TS EN ISO 10140-5 standard. This method has been used extensively since 1968. This standard also uses single number calculation for impact sound reduction in the light of collected data during TS EN ISO 10140-3: 2011 tests and also evaluates the decrease of weighted impact sound pressure level by floor coverings on light slabs. Single number value for impact sound insulation grading in the light of one-third octave band measurements and single number quantities for impact sound insulation grading in the light of octave band measurements are important points for the standard. Table 4 demonstrates the basic 1/3 octave band ISO 717-2: 2013 field descriptors (single-number quantities) and the spectrum adaptation terms intended for specification. In addition, the spectrum adaptation terms in TS EN ISO 717-2: 2013 change according to different spectra of noise sources so Table 5 shows the intended uses of spectrum adaptation terms according to TS EN ISO 717-2: 2013.

Spectrum adaptation is an important point to consider. It is adding value to single number quantity to calculate non-weighted impact sound level to show typical walking noise spectrum features. According to the standard TS EN 10140-3:2011, normalized impact sound pressure level is symbolized as 'L_n' and the value is found with this formula;

$$L_n = L_1 + 10\lg \frac{A}{A0} \text{ dB}$$

$$A = 0{,}16\ V/T$$

L_n=Normalized impact sound pressure level

L_1=Impact sound pressure level in 1/3 octave band

A = Measured equivalent absorption area of receiver room.

A_0= Reference equivalent absorption area, 10m^2

V= Knowledge of the typical volume, m^3

T=Knowledge of the resonance time, s

(Retrieved from TS EN ISO 10140-3: 2011)

Table 4. Overview ISO 717-2 descriptors for evaluation of impact sound insulation in buildings (Retrieved from Cost Action TU 0901, 2014).

ISO 717-2 Descriptors for Evaluation of Impact Sound Insulation	
ISO 717:2013 descriptors for evaluation of field sound insulation	**Impact sound insulation between rooms (ISO 717-2)**
Basic descriptors (single-number quantities)	$L'_{n,w}$ $L'_{nT,w}$
Spectrum adaptation terms (listed according to intended main applications)	None C_1 $C_{1,50\text{-}2500}$
Total number of descriptors	2 x 3= 6

Table 5. Relevant spectrum adaptation term for different types of noise sources (Cost Action TU 0901, 2014).

Relevant Spectrum Adaptation Chart	
Type of noise source	**Relevant spectrum adaptation term**
-Living activities (talking, music, radio, tv) -Children playing -Railway traffic at medium and high speed -Highway road traffic > 80 km /h -Jet aircraft short distance -Factories emitting mainly medium and high frequency noise	C (Spectrum 1: A-weighted pink noise)
Urban road traffic Railway traffic at low spreads Aircraft propeller driven Jet aircraft large distance Disco music Factories emitting mainly low and medium frequency noise	C_{tr} (Spectrum 2: A- weighted urban traffic noise)
ISO Tapping machine	C1

To specify single number value for rating impact sound insulation, obtained data from the TS EN ISO 10140-3:2011 tests for one-third octave band 100 Hz-3150 Hz frequencies and for octave bands 125 Hz – 2000 Hz frequencies results are compared with each other. For comparison method, both one-third octave bands and octave bands to evaluate measurements normalized sound pressure level (L_n), normalized impact sound pressure level (L'_n), and standardized impact sound pressure level (L_{nT})

measurement data should be given with decimal place. Amount of unwanted deviations should be as big as possible but until it cannot be bigger than 32, 0 dB, related reference curve should be moved to measurement curve by 1 dB enhancements for one-third octave bands. An unwanted deviation in specific frequency occurs when measurement results exceed the reference value. Only the unwanted deviations should be considered during the tests. After movement of the reference curve are (L_{nw}), (L'_{nw}), (L_{nTw}). The impact sound reference values shown in

Table 6. Impact sound reference values (TS EN ISO 717-2, 2013)

Impact Sound Reference Curve Values																
Frequency Hz	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150
1/3 Octave band	62	62	62	62	62	62	61	60	59	58	57	54	51	48	45	42
Octave band	67			67			65			62			49			

A weighted decrease value of the impact sound pressure degree ΔLw is calculated with these formulas;

$$L_{n,r} = L_{n,r,0} - \Delta L$$

$$\Delta L_w = L_{n,r,0,w} - L_{n,r,w} = 78 \text{ dB} - L_{n,r,w}$$

$L_{n,r}$= The performed floor covering with reference slab calculated normalized impact sound pressure level

$L_{n,r,0}$= Normalized impact sound pressure level of reference slab.

ΔL=Decreasing level of measured impact sound pressure level according to TS EN ISO 10140-1

$L_{n,r,w}$= The performed floor covering with reference slab calculated nominal normalized impact sound pressure level

$L_{n,r,0,w}$= Reference slab nominal normalized impact sound pressure level

(Retrieved from TS EN ISO 717-2: 2013)

There are many different descriptors used by the countries who participate in Cost Action TU0901. The action provides a theoretical translation to see differences of recommendations clearly. Theoretical relationships between various quantities can be deduced from basic building acoustic equations and definitions. In addition, these relationships involve the geometry of the situation for which assumptions will have to be made (Cost Action TU0901, 2014). These relationships do not depend on frequency so they can be applied to different frequency ranges. Therefore, the following formula can be used for the descriptors

$$L'_{nT} = L'_n - 10\lg \frac{0{,}16\ V}{T0\ A0}\ \text{dB}$$

L'_{nT} = Normalized impact sound pressure level

L_n = Normalized impact sound pressure level

A_0 = Reference equivalent absorption area

T_0= Resonance time in receiving room

V= Knowledge of the typical volume

(Retrieved from Cost Action TU 0901, 2014).

2.3. Expanded Polystyrene (EPS) in Construction

Expanded polystyrene is a kind of monomer styrene based closed cell construction material. The EPS has been accepted as a well performing and sustainable insulating material for more than 40 years. The EPS holds a market share of 35% of the total construction thermal insulation market in Europe and also in Turkey (Eumeps, 2016). The EPS provides an exceptionally lightweight solutions to so many applications in construction because the EPS is a result of advanced manufacturing technologies (98% air captured within a 2% cellular matrix) (EPS Briefing, 2016). In addition, this lightweight structure of the EPS provides advantages in on-site handling and transportation, brings significant economic benefits and also reduces health and safety risks associated with the lifting of heavier materials considerably (EPS Briefing, 2016). Therefore, it is an excellent substitute for infill materials and ballast. At the same time, it also brings load and fill times down in projects. In addition to this, the EPS is used in many different applications like roof, floor and wall insulation, sub-structure and void-fill blocks for civil engineering, foundation systems, clay heave protection, bridge, rail and road widening schemes, underground heating system support, interior and exterior decorative moldings.

The EPS is produced from solid beads of polystyrene, and it is a lightweight, rigid, plastic foam insulation material (Eumeps, 2016). Expansion is achieved by virtue of small amounts of pentane gas dissolved into the polystyrene base material during production (2016). The perfectly closed cells of EPS are formed by gas expands under the action of heat, applied as steam and these cells expands approximately 40 times bigger than the volume of the original polystyrene bead (2016). Then, the EPS beads are molded into appropriate forms according to their usage field. The flow chart summarizes the process (see Figure 2)

EPS has high strength and structural stability. In spite of its light weight structure, its unique matrix structure of EPS creates strong reinforcement against compressive strength and block-rigidity (EPS Briefing, 2016). This feature makes it ideal for use in many construction and civil engineering applications such as road or railway infrastructure or hollow core slab systems (EPS Briefing, 2016). Strength tests performed on EPS for 30 years demonstrate that the EPS under 100kPa show creep deformation of less than 1,3% and the EPS stability does not deteriorate with age (EPS Briefing, 2016).

High thermal insulation qualities of the EPS with BRE “A-Plus” rating shows that it is the perfect choice for use in under floor, between floor, walling and roofing applications where it is also able to give a constant insulation value across the full service of the building (EPS Briefing, 2016). Thermal conductivity testing of the EPS according to standard DIN 52612, 0, 0345 W/mK was well within the originally specified standard requirement of 0,040 W/mK (EPS Briefing, 2016).

EPS PRODUCTION PROCESS FLOW CHART

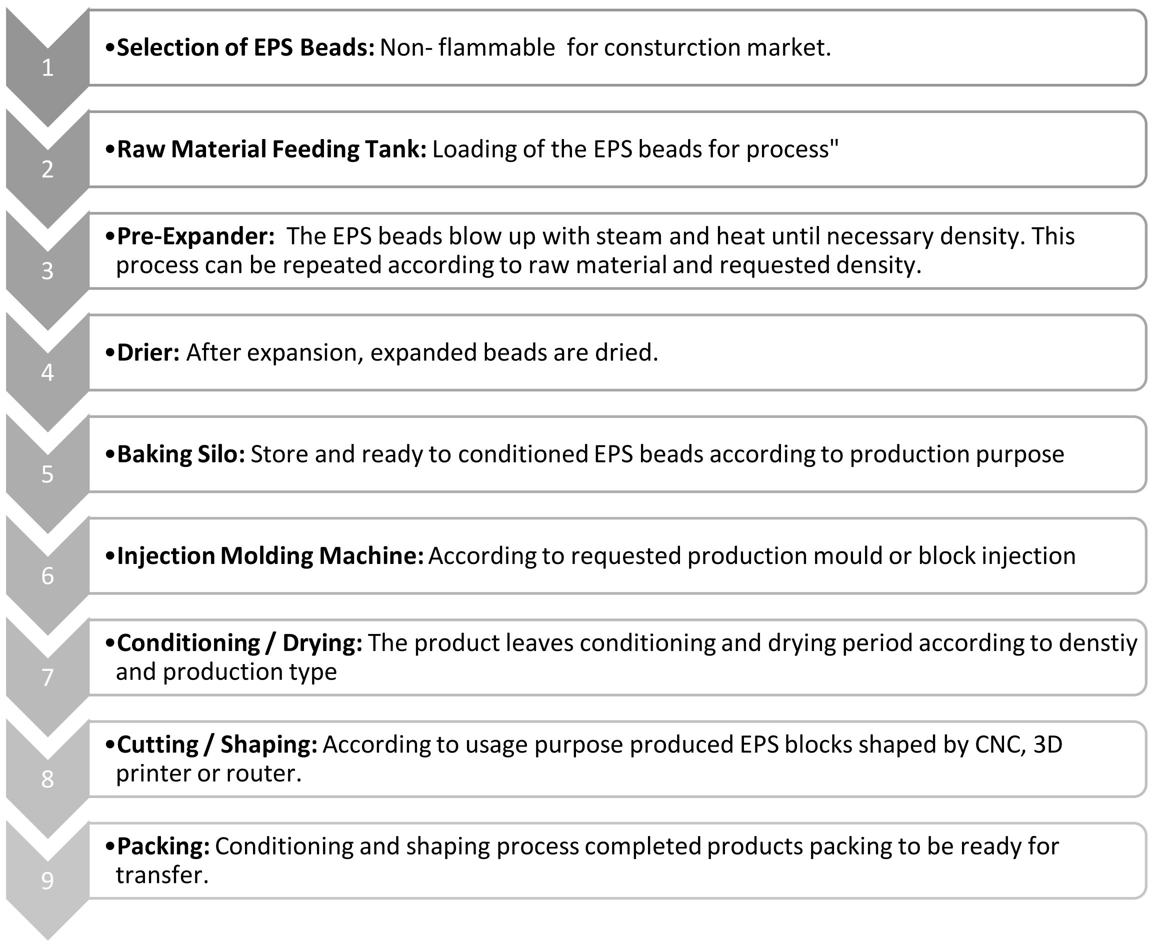


Figure 2. Production process of the EPS (by Erdemli)

The EPS is a well-established material for the construction market and offers proven and economic solutions for building costs and insulation budgets. The material is 20%

cheaper than polyurethane or mineral wool so when the insulation performance of these materials are taken into account, it can be concluded that EPS itself costs less than these competing materials. 30 year long underground tests show that the EPS usage does not need any waterproof layer and samples of the EPS used in the tests absorbed less than 4% water (EPS Briefing, 2016). Thus, it can be concluded that EPS shows better performance than other foamed plastic materials (EPS Briefing, 2016). Easy cutting or molding of EPS provides fast shaping in factory or on site preparations of complex shapes to match the most demanding architectural, civil engineer and design requirements. Civil engineering applications are one of the common topics among EPS usage areas, and it involves concrete slab filling materials (Eumeps, 2016). EPS filling material for hollow core slab systems has easy handling and installment then the other materials. Besides, it has low thermal conductivity, versatility, low weight, efficient mechanical and chemical resistance, low water absorption and ageing resistance (EPS Industry Alliance, 2016).

EPS Industry Alliance highlight that when EPS easy used in combination with other building materials effectively reduces the transmission of airborne sound through partitioned walls, ceilings and floors (EPS Industry Alliance, 2016). The resistance performance of EPS to airborne sound transmission is not only related with characteristics of the material placed in the path of sound waves but also related with method of the construction (EPS Industry Alliance, 2016).

As a result, the EPS is a very efficient and useful material for construction market as there are many advantages of it for the construction system, workmanship, investment budget and environment. However, its acoustic performance is not determined clearly and it does not have a strong place in the market with its acoustic performance.

2.4 Studies about Impact Sound Insulation and Expanded Polystyrene

Impact sound is disturbing noise for people who especially live in multi-storey buildings. Therefore most recent European acoustic codes and regulations demand a maximum value for impact sound insulation on slabs. The improvement on acoustic comfort in buildings is frequently achieved through technical solutions such as application of lightweight and low stiffness materials between the structural slab and the finishing covering (Kim, Jeong, Yang & Sohn, 2009). In general in built environment, many buildings demand the implementation of technical solutions like floating floors with resilient layers under finishing layer. The sound energy dissipated in the resilient layer leads to considerable reduction on the impact sounds transmitted through structural elements (Branco & Godinho, 2013).

Branco and Godinho (2013) designed and analyzed an alternative solution to floating concrete slabs and pavements by using light-weight soft layers containing expanded polystyrene, cork and expanded clay granulates, applied over the structural concrete slab. This study aims to quantify and compare enhancement on the reduction of impact sound transmission provided by lightweight mortar layers. The study is based on laboratory tests conducted according to ISO 140-8 and normalized sound insulation and sound level reduction was computed. The small sized four types of mortar samples were tested on a standard weight concrete slab and were analyzed in the light of ISO 717-2 to match with the real size. These four types of mixture and standard mortar were tested in three different specimen size to analyze specimen size effect. Different size of same mortars showed similar variation about impact sound reduction but some discrepancies between values obtained were noticed between smaller and bigger samples especially for lower frequencies (Branco, Godinho, 2013). These five mortars show very distinct acoustic behavior and the standard weight concrete slab contributed to sound level reduction in very small quantities as expected because of its high stiffness of material rather than other lightweight mixtures ((Branco & Godinho, 2013). Lightweight mortars contain expanded cork and polystyrene granulates show better performance when compared with the others especially on higher frequencies (Branco & Godinho, 2013). On the other hand, during tests, when the effect of mortar thickness are considered it was observed that demonstrate that when thickness is increased, mortars show better impact sound insulation performance at higher frequencies (Branco & Godinho, 2013). This study also aimed to see the effects of surface finishing, so the mortars were also tested with wood covering, wood and cork covering, and finally ceramic tile covering. Floating wooden floor and cork granulated mortar combination demonstrated a significantly higher performance especially above 500 Hz (Branco & Godinho, 2013). At the end of the tests, especially expanded polystyrene (EPS) and cork granule integrated mortars showed much better performance than the standard mortar, expanded clay granulates and expanded clay mortars (Branco & Godinho, 2013). The usage of cork granulates demonstrate better results than the other ones thanks to its high flexibility and resilience of the material (Branco & Godinho, 2013). Without floor coverings, a sensible impact sound reduction was recorded especially at higher frequencies (Branco & Godinho, 2013). The finishing coverings on mortars demonstrate a similar performance; however, when a resilient underlay was used, small enhancements on impact sound reduction were registered (Branco & Godinho, 2013).

The conducted study by Najim and Hall (2012) aimed to determine mechanical and dynamic properties of self-compacting concrete which contains different amounts of rubber aggregates. The results showed that the dynamic modulus and ultrasonic pulse velocity within rubberized concrete decreased as the proportion of rubber substitution was increased (Najim & Hall, 2012). In addition, the rubberized concrete perform great impact vibration damping behavior in all test situations, with up to 230 % enhancement in damping ratio and damping coefficient (Najim & Hall, 2012). On the other hand, the study investigated the characteristic of lightweight aggregate concrete with volume of entrained air. Effects of lightweight aggregate and entrained air on density, porosity, dynamic elastic modulus and acoustic transmission loss was determined (Najim & Hall, 2012). The sufficient acoustical insulation performance of the lightweight aggregate cellular concrete with adequate amount of air entraining agent was detected (Najim & Hall, 2012).

The recent studies have shown that different granules containing mixtures may be useful to reach desirable impact insulation performance. Especially in recent years, the use of recycled materials to increase both acoustical comfort and environmental awareness is a very common method. Therefore, granulated rubber which is produced from automotive tires was used to experimentally investigate the acoustical properties of new underlay

(Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). In addition, the experimental results obtained in the laboratory enhanced a new resilient layer (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). The main raw material was the fluff with different particle size which is from the shredding of tires of heavy vehicles. Moreover, vermiculite, expanded polystyrene and cement mortar were also other materials used during the tests. All of the preferred raw materials were mixed with high viscosity polyurethane resins as a binder to increase porosity and make it easy to mix rubber fluff with binder efficiently (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). The Cremer's model was preferred to evaluate the theoretical acoustical performance of the selected raw materials. The measurements of the impact sound reduction of the prepared mixtures were examined in the light of EN ISO 140-8 to compare the theoretical and real performance of these new resilient layers (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). Variety of microstructures of the samples presented large differences in their porosity values during the performed tests, and this diversity provides very different porous microstructures and consequently different acoustical properties (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). The impact sound tests results according to Standard EN 29052-1 for new layers in frequencies 42.5 Hz and 100.2 Hz were comparable to the values obtained from commercial layers tested under the same conditions (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). The results surprisingly show that the used fluff with %90 percentage in thickness 12 mm and 10.2 mm performed better performance about impact sound improvement (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). The compressibility is also an important point for impact sound insulation in layers because the mechanical deformation of resilient materials reduces their dynamic stiffness so they lose their acoustical properties (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). Therefore, deformation of the samples were also taken into account. In general, the samples adequately competed with commercially accepted and available acoustical products and in some cases show better performance than conventional layers. Therefore, elastomeric waste, called ground tire rubber can be recycled into acoustical underlay products (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). The resilient layers, composed of only recycled tire rubber and a binder performed better than other mixtures which include EPS, mortar, and vermiculite in different proportions (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011). Application of these new products with airless gun with a special tip provide covering for the entire floor without discontinuities so the new layers demonstrate better impact sound insulation performance by lower thickness (Maderuelo-Sanz, Martín-Castizo &Vílchez-Gómez, 2011).

In addition to creating resilient layers to control impact sound, constructing a floating floor on construction slab is another sufficient solution. A floating floor construct basically lightweight timber floor on battens is separated from a concrete structural floor by a resilient layer. The study conducted by Stewart and Craik (2000), presents a theoretical model to predict bending wave transmission through parallel plates connected by resilient line. To predict transmission through a chipboard floating floor attached to battens and the results of the model were used in a statistical energy analysis framework (Stewart & Craik, 2000). To get sufficient results, all acoustical transmission through cavities and cracks were considered (Stewart & Craik, 2000). The results showed that missing of resilient layer causes increase of sound transmission ratio significantly through the battens (Stewart & Craik, 2000). Moreover, comparisons between measured data and predicted results demonstrate good agreement especially at low and mid frequencies when a resilient layer was available (Stewart & Craik, 2000). The full size floor tests demonstrate that the coupling through the batten was a dominant path if there is any interlayer and this case provides better match between the measured and predicted results (Stewart & Craik, 2000). Nevertheless, when a resilient layer was added to the system, the structural coupling was predicted as being negligible compared with acoustic coupling through the cavities between the battens (Stewart & Craik, 2000). The agreement of measured and predicted outcomes is accepted as reasonable at low frequencies; however, the theoretical model significantly underestimates coupling at the higher frequencies (Stewart & Craik, 2000). According to Stewart and Craik (2000), this situation may not provide successful results so alternative methods of modelling the boundary where localized stress fields are predicted can be considered.

All the studies mentioned above emphasize the effectiveness of creating a resilient layer or floating floor by differentiation of its layers and ingredients on existed slabs to increase the impact sound insulation. This study aims to reach demanded impact insulation by using only EPS block as a filling material on one way hollow core structural slabs systems without creating extra supportive layers. This method aims to deal with impact sound transmission problem at the level of creating system during construction.

There are many studies available about the EPS as a construction material. These studies embrace technical features of the EPS as a construction material. In addition, these studies show possible reaction against constructional forces, the factors affecting the product properties and possible performance developer combinations with other construction materials. EPS has been used as a thermal insulation material commonly for more than 40 years so there are many studies available about the thermal insulation performance.

External thermal insulation of the dwelling walls have been used increasingly in recent years to increase thermal comfort of the interiors and decrease energy consumption of the buildings. Especially in built environment before 2000s, heat lose precautions were not satisfying so, for this kind of buildings thermal insulation became an important issue. Therefore, most of the submitted studies take EPS into account as a thermal insulation material. The study conducted by Florea (2012) in Romania scale highlight that as a rigid and nonflammable material EPS is a very common material for thermal insulation due to its easy application, low weight structure, easy availability and cost effectiveness. In addition, the study highlights limitation of EPS material use as a thermal insulation material on buildings higher than 5 floors in Romania because of difficult intervention of the firemen in case of fire risk of intoxication with gases resulted from polystyrene burning (Florea, 2012).

There are several important points available at the production process of the EPS as mentioned in the section “Expanded Polystyrene in Construction” and this step directly affects the thermal insulation value of the EPS panels. The EPS beams blow up until demanded density, at this point, reaching exact and true density is very important. For the expanded polystyrene boards, the density was accepted as the only dominant factor affecting product properties until recent years. The EN16163 standard performs at the same approach and thermal insulation board properties were classified independent of the density. The study of Mıhlayanlar, Dilmaç and Güner (2007) demonstrate that the density is the main factor for controlling the product properties of EPS by a ratio of 90-95%. Nevertheless, production process parameters affect the product properties by ratio not much more than 10%. The extraordinary results are not possible by just changing the production process parameters without changing the density (Mıhlayanlar, Dilmaç & Güner, 2007). During the study, which density and production prove parameters influence the thermal conductivity and mechanical properties were examined by the EPSDER / PÜD Laboratory and the results were evaluated. The production process parameters and the product properties are the bending strength and the declared thermal conductivity corrected for thickness (10%), and the compressive stress at 10%, deformation is 5% (Mıhlayanlar, Dilmaç & Güner, 2007).

The conducted study by Uzun and Unal (2016) mentioned importance of structure and density of pore for thermal insulation performance because thermal conductance is related with these two parameters directly rather than any other parameters. Increasing quantity of pored structure of the EPS is affecting the density of the EPS blocks and this situation causes that when density is increased, as a construction material EPS is also increased in a unit volume according to a ratio (Uzun and Unal, 2016). Therefore the thermal conductivity of EPS is also predicted (Uzun and Unal, 2016). To see effects of increasing quantity of pore structure on density, a laboratory test was conducted and the performed laboratory tests were based on taking high detail and sensitive 100 and 1500 photography of the pore structure of EPS (Uzun and Unal, 2016). The results according to taken 100 and 1500 enlargement photos in laboratory, numerical model is not possible for EPS because of that EPS doesn't have a proper geometric structure and, the structure randomly occurred (Uzun & Unal, 2016). Moreover, the received data at the end of the tests demonstrate that when density is increased, thermal conductivity value is decreasing even if it is so minimum (Uzun & Unal, 2016). In addition to this, during the study, EPS boards containing an additive like carbon granule has lower thermal conductivity levels than the white pure EPS with so low ratio difference was also proved (Uzun & Unal, 2016).

Another study was conducted to reach more correct results about thermal conductivity values of construction materials, knowing physical properties of materials and using appropriate techniques. Determining thermal conductivity coefficients after production phase of construction materials may force producers to produce high quality materials with true thickness of insulation materials to reduce extra load in buildings and effective economic conditions (Yucel, Basyigit and Ozel, 2003). Controlling and predicting long term characterization of a structure is important for total insulation of a building so, in the process of assessing design values for thermal conductivity of insulating materials, density, thermal conductivity, material class and mechanical properties of the insulation is very important (Yucel, Basyigit and Ozel, 2003). Moreover, physical properties like unit weight, viscosity, and thermal conductivity coefficients of new materials have to be determined for efficient building construction (Yucel, Basyigit and Ozel, 2003). The study has followed "Feutron Type Plate Method" with samples by 25cm x 25cm x 7cm to determine thermal conductivity coefficient with conduction, as a very common test method and technique in order to determine thermal properties of boards. Unit weights (density) 10, 15, 20, 25, 30 kg/m^3 as a commonly preferred unit weights on market were selected to determine thermal conductivity coefficients. EPS loses its physical properties at 105 ^{0}C so the specimens were dried 24 hours at 105 ^{0}C to change weight under normal atmospheric pressure before the tests. At the end of the study, even only one value was given in literature and standards like TS 825 and DIN 4108 for thermal conductivity coefficient of EPS, determined results during the test demonstrate that thermal conductivity coefficient changes reversely with density (Yucel, Basyigit & Ozel, 2003). Thus, the decrease of thermal conductivity coefficient is provided by increasing the number of EPS grains in unit volume and this results in less void volume between grains and also an increase in the number of pores in the EPS grains (Yucel, Basyigit & Ozel, 2003). In addition, a decrease in the amount of total voids in EPS will result in an increase in compacity so thermal conductivity coefficient value may increase (Yucel, Basyigit & Ozel, 2003).

A study conducted by Ferrándiz-Mas and García-Alcocel (2013) focused on the durability of expanded polystyrene foam on the Portland cement mortars. Water absorption capillary of the mixture was determined by mercury intrusion porosimetry impedance spectroscopy and open porosity methods. The effects of heat cycles and freeze-thaw cycles on compressive strength were examined. During the test phrase, scanning electron microscopy, and an air entraining agent, water retainer additive and superplasticizer additive were preferred for improving the workability of mortars. The results demonstrate that EPS in prepared mortar samples enhance their durability thanks to its capillary absorption coefficient of EPS mortar mixtures (Ferrándiz-Mas & García-Alcocel, 2013). Durability of the samples increased by preferred additives allows the matching of mortars with high EPS quantity (Ferrándiz-Mas & García-Alcocel, 2013). Moreover, EPS demonstrated significant positive enhancements on the compressive strength of mortars subjected to heat cycles, and the enhancement based on improvements in the microstructure of cement mixtures as well as in the cement-EPS interface (Ferrándiz-Mas & García-Alcocel, 2013). In addition to this, EPS absorbs some of crystallization pressure of ice and contribute to a reduction of mortar damage and maintain durability after freeze-thaw cycle completed (Ferrándiz-Mas & García-Alcocel, 2013).

Management of the waste EPS is an important topic for the environmental issues. Therefore, many studies were applied to show performance of the waste EPS with mortar, cement and gypsum mixtures. A study by Sahin and Karaman (2012) aimed to investigate effect of waste expanded polystyrene and pumice aggregate on strength and thermal conductivity of gypsum blocks. In this study compressive strength, water absorption and thermal conductivity of the produced samples were analyzed by laboratory tests and the samples were prepared with the materials manufactured according to related Turkish Standards to be used in construction (Sahin & Karaman, 2012). The compressive strength tests according to TS 451: 1983 and thermal conductivity tests according to TS 825: 1999 were conducted (Sahin & Karaman, 2012). According to obtained results from the laboratory tests, the samples produced with EPS, gypsum and pumice showed sufficient strength so it creates potential for replacement for conventional hollow burnt clay bricks and hollow concrete blocks (Sahin & Karaman, 2012). The low density of EPS gypsum blocks has the potential to reduce the dead weight in construction (Sahin & Karaman, 2012). The thermal conductivities of the tested specimen's values were lower than the traditional gypsum blocks so, thermal insulation properties were sufficient due to tested EPS and pumice (Sahin & Karaman, 2012). Water absorption quantities of the samples varied according to ratio of the used EPS and pumice granule in the whole volume significantly, and the samples demonstrate low water absorption ratio rather than other wall building materials like hollow concrete blocks and gas concrete (Sahin & Karaman, 2012).

The concept of 'sustainable development' has spread in recent years so new composite materials have been presented each passing day. The study carried out by Agoua, Allognon-Houessou, Adjovi and Togbedji (2013) tested a new composite material by manufacturing recycling sediments of wood and polystyrene as a composite. The composites contain chips or sawdust of wood sorted in particles of varied dimensions and mixed according to a granular composite well defined were assembled with glue produced form polystyrene of packing dissolves in a solvent. The Thermal Field in Stationary Regime which is called "Method of Comparison" or "Method of Plexiglas Standard" and based on the principle of the well-known method of the hot plate was performed for the tests through using an experimental device in Ecole Polytechnique d'Abomey-Calavi, Benin (Agoua, Allognon-Houessou, Adjovi and Togbedji, 2013). The results of performed tests on the 9 different samples with different mixture ratio showed that the glue produced from polystyrene dissolves in petrol is compatible with particles of wood used in buildings (Agoua, Allognon-Houessou, Adjovi & Togbedji, 2013). The results also show that thermal conductivity increases when the content of the glue in the samples is increased and, when the wood is mixed with too much glue, the glue distributes itself on the surface of the composite so this contributes to the conduction of heat in the material (Agoua, Allognon-Houessou, Adjovi & Togbedji, 2013). Therefore, the method creates economic and environmentally friendly composites to use in insulating material for imitation ceilings and dividing walls (Agoua, Allognon-Houessou, Adjovi & Togbedji, 2013).

The study conducted by Demirboga and Kan (2013) also aimed determine a way of recycling expanded polystyrene by thermal modification to create a lightweight aggregate to increase workability, density thermal conductivity and shrinkage of concrete. Therefore, the aggregate was used as a coarse aggregate in production of concrete for possible application of low strength concrete like masonry units and semi structural purposes (Demirboga & Kan, 2013). An artificial lightweight aggregate produced from waste expanded polystyrene foams provide many advantages such as flexibility, cost effectiveness, reducing dead load, improved cyclic loading structural response, longer spans, thinner sections, smaller size structural members and lower foundation costs (Demirboga & Kan, 2013). The laboratory tests according to standard ASTM C 1113-90 were performed on the prepared sample prism aggregates. Differentiation on thermal modified waste expanded polystyrene aggregate ratio in concrete affect workability, density and shrinkage of the prepared samples (Demirboga & Kan, 2013). The thermal modified waste expanded polystyrene aggregate contain mixtures which decreased workability (Demirboga & Kan, 2013). The dry densities of the concrete, density value decreased from 2025 to 980 kg/m^3 so, thermal conductivity of concrete also decreased around 70% by increasing thermal modified waste expanded polystyrene aggregate ratio in the concrete (Demirboga & Kan, 2013). Moreover, the study demonstrated that thermal conductivity is so highly sensitively to the change in density rather than the shrinkage (Demirboga & Kan, 2013).

There are many studies available about EPS use as thermal insulation material, its wastage management, characteristics in usage, parameters of production and usage or performance evaluation when mixed with any other materials. Besides, as a closed cell insulation material, studies about acoustical performance is very limited. According to studies of EPS Industry Alliance (2016) to diminish noise transmission in different structures EPS applications perform better solution because simply a typical approximately 8 cm wall with EPS insulation and 0,6cm gypsum board on both sides can reduce sound transmission between spaces up to 36 dB . The EPS comes in different thicknesses so when component materials such as the wall system and finishing are factored in, sound abatement properties can increase up to 52 dB depending on the thickness of the application. This is competitive performance when the sound audibility of speech 25 dB is considered (EPS Industry Alliance, 2016). Nevertheless, the submitted values about sound isolation are not a result of a clearly performed laboratory test. In addition, the values do not claim sound isolation according to source type of the sound like airborne or impact. Moreover, this is not enough to determine and analyze impact sound insulation of a slab system.

The submitted user guide book by Ineos Styrenics (2015) , one of the biggest EPS raw material producers in Europe, highlights that, preferring Styrocell EPS foam board in combination with other building materials, effectively reduces transmission of airborne sound in walls, roofs and floors. Most of the studies in literature recommend the use of open-cellular foam and fibrous materials for airborne sound insulation applications. However elasticized EPS foam board is not well known in this application and is often overlooked (Ineos Styrenics, 2015). To determine air borne sound insulation property of construction elements of infinite length has been developed by Shell Research and the Acoustics and Thermal physics department of the Katholieke University of Leuven and, this model can calculate the acoustic insulation properties of a multi-layer construction element like wall or floor by using the physical properties of the materials applied in construction element (Ineos Styrenics, 2015). According to this method, the two outer layers provide the mass and the EPS layer in the middle functions as a spring and the heaviest layer due to its thickness and density determines the critical frequency (Ineos Styrenics, 2015). The properties of the elastic middle layer determine the respiration frequency (Ineos Styrenics, 2015). The critical frequencies of common building materials like cement and concrete are very close to frequency of common speech. However, high mass of these kind of materials compensate this kind of disadvantages and this situation even leads to excessively heavy buildings (Ineos Styrenics, 2015). Besides, EPS foam board produced from elasticized by compression of the EPS block is used with combinations with other buildings demonstrate effectively reduced airborne sound transmission (Ineos Styrenics, 2015). The performed tests demonstrated that increased thickness (up to 20 cm), ratio of elasticized under hydraulic press at compressive loads well above its elastic limit and density also improve the acoustic performance of the EPS boards (Ineos Styrenics, 2015). However, the firm declares that the standard EPS boards simply cut from blocks is not effective for airborne sound (Ineos Styrenics, 2015).

In recent years, to enhance thermal insulation performance of the EPS, integration of graphite flakes into polystyrene structure is so common. The graphite embedded EPS panels (grey or black ones) increase the thermal conductivity by reflecting and absorbing radiant energy as declared through recent study of Park, Kim, Oh, and Cho (2016). In addition, enhancement of the thermal insulation performance of graphite embedded EPS gives chance to select thinner EPS boards (Park, Kim, Oh, & Cho, 2016). In addition, deformed structure of EPS through graphite induction to structure is assumed to contribute to the reduction in dynamic stiffness (Park, Kim, Oh, & Cho, 2016). This embedded study aimed to investigate the mechanical properties of compressively deformed graphite integrated EPS and its sound insulation performance for the enhancement of low frequency sound insulation material. The experimental results demonstrate that embedding graphite is decreasing stiffness and the compressive deformation result in a sufficient reduction in the dynamic stiffness for insulation (Park, Kim, Oh, & Cho, 2016). Primary components of the low frequency floor impact source while structural strength against the nominal load of the floor was maintaining (Park, Kim, Oh, & Cho, 2016). The conducted laboratory vibro-acoustic tests results show that the impact sound insulation efficiently improved above 60 Hz, compared to the uncompressed EPS due to the decreased natural frequency by reduction in the stiffness of the compressed EPS (Park, Kim, Oh, & Cho, 2016). Besides, the coupled bending wave field in the base slab is released between 35 and 60 Hz as the natural frequency decreases, which disturbs the isolation (Park, Kim, Oh, & Cho, 2016). Deteriorated isolation efficiency because of the decoupled wave field affect fewer than the enhancement from the reduced natural frequency (Park, Kim, Oh, and Cho, 2016). It should be considered that all findings in this study are based on investigations of a massive floating plate 5 cm thick mortar bed on a concrete slab so the results cannot be suitable for other slab types.

The EPS White Book (2016) background information for standardization stated that the dynamic stiffness is needed for applications where acoustical performances have to be assessed. In addition, low value of dynamic stiffness lead to a high sound reduction performance (EPS White Book, 2016). Moreover, the dynamic stiffness is needed to calculate the weighted impact sound reduction index of intermediate floors with a floating floor finish (EPS White Book, 2016). Detailed information and calculation of impact sound reduction EN12354-2 and for testing dynamic stiffness EN13163 standards or equivalent standards should be taken into account. However, according to the mentioned application example in the EPS White Book (2016), these standards and calculations are applicable for homogenous slabs and floating floors on it. Furthermore, there is not any other detailed information or performance test method for non-homogenous slabs acoustical performance.

In conclusion, literature review has given us the opportunity to see that there are many studies available to increase impact sound insulation performance of the slabs, characteristics of EPS and thermal insulation performance and efficient re-use methods of EPS. Moreover, there are studies carried out to control and enhance impact sound insulation in dwellings by regulations and standards in many European countries. Turkey has very well organized EPS manufacturers in the construction market and EPS is used widely as a filler material in large quantities. In addition, one way hollow core slab with EPS filler construction method is widely preferred. However, Turkey does not have any regulations and standards about sound insulation in dwellings yet. Also impact sound insulation of one–way hollow core slabs with EPS filler and the effects of EPS fillers' density have not been studied and tested even though there are many occupants living in one-way hollow core slab with EPS filler preferred dwellings who complain about especially impact sound transmission problem in their buildings. Therefore, this study aims to determine impact sound insulation performance of one-way hollow core slab system with EPS filler and the effects of preferred density of EPS filler to enhance acoustical performance of interiors in terms of impact sound.

CHAPTER III

THE EFFECT OF DENSITY ON IMPACT SOUND INSULATION OF THE EXPANDED POLYSTRENE (EPS) BLOCK USED AS FILLER IN ONE WAY HOLLOW CORE SLAB IN DWELLINGS

3.1. Design of the Study

The purpose of this study is to determine impact sound insulation value of EPS blocks in one way hollow core slabs through examining impact sound insulation performance at 1/3 octave band variations when the density of EPS block fillers changes. The 10 kg/m^3 and 16 kg/m^3 EPS block fillers used in this study. The TS EN ISO 10140-3, measurement of impact sound insulation laboratory tests were performed two times on two different slabs with different densities in the Turkish Standard Institute Tuzla Acoustic Laboratory.

3.1.1. Research Question

The research questions of this study are as follows:

1. What is the impact sound insulation value of the 10 kg/m^3 and 16 kg/m^3 EPS block fillers in one way hollow core slabs at 1/3 octave band?

2. Are there any differences between 10 kg/m^3 and 16 kg/m^3 EPS block fillers on impact sound insulation?

3.1.2. Hypothesis

The hypothesis are

1. The weighted normalized impact sound pressure level (L_{nw}) of one way hollow core slabs with EPS filler has lower performance than the given values in the literature.
2. If the density of the expanded polystyrene block fillers is increased, impact sound insulation performance increases

3.2. Methodology

This study aims to detect impact sound insulation value of 10 kg/m^3 and 16 kg/m^3EPS block fillers in one way hollow core slab system at 1/3 octave band, and also investigate the effects of density differences on impact sound insulation. When we look at the literature, we see that most studies about impact sound insulation have been performed in laboratory by small samples and then transferred to real sizes with different techniques. However, this transmission from small samples to real size samples do not reflect reality. The one way hollow core slab system is commonly preferred by civil engineers in Turkey. However, there are no regulations or standards used to maximize interior acoustical comfort level and even impact sound insulation is a dramatically increasing problem of the one way hollow core slab systems when the complaints of the users who live in one way hollow core slab preferred adjoining dwellings are taken into account. Thus, to be able to reach exact quantitative results of impact sound insulation of one way hollow core slab system with EPS filler and effects of density differences of the fillers, laboratory tests were performed on two different EPS filler used slabs. The laboratory tests were performed in Turkish Standard Institute Tuzla Acoustic Laboratory by TS EN ISO 10140-3: 2011 Acoustics - Laboratory measurements of sound insulation of building elements- Part 3: Measurement of impact sound insulation. After measurement of the slabs impact sound insulation in laboratory, collected data has been analyzed in the light TS EN ISO 717-2: 2013 – Acoustics. Rating of sound insulation in buildings and of building elements – Part 2: Impact sound insulation. The flow chart below summarizes the steps of the study (Figure 3).

STEPS OF EPS PRODUCTION

1. Production of demanded EPS Block Fillers by Basaş Strafor
2. Conditioning of the EPS Fillers around 3 week to use in construction by Basaş Strafor
3. Cutting and shaping of EPS blocks according to the project by Basaş Strafor
4. Preparation of materials for construction of the slabs; concrete, iron profiles, eps
5. Construction of the test slabs in the TSE Tuzla Acoustic Laboratory
6. Conditioning the slabs for 3 weeks before the performing tests
7. Performing TS EN 10140-3 laboratory tests in Tulza Acoustic Laboratory
8. Submission of the reports of the tests in the light of TS EN ISO 717-2:2013
9. Evaluating the tests results and preparing final reports
10. Evaluation of obtained results with the study supporters
11. Organization of a seminar with the partner firms, institutes and universities

Figure 3. Flow chart of the study process (by Erdemli).

3.3. Research Context of the Study

3.3.1. Measurement setting

TS EN ISO 10140-3:2011 is aimed to be used to measure impact sound pressure level of the slab applications in a laboratory environment designed according to TS EN ISO 10140-5: 2013.

The study is based on commonly used one way hollow core slab systems in multistory dwellings in Turkey, so the sample slab was retrieved from the in situ applications. The test sample has been designed according to submitted information about dimensions of the test frame which is suitable for the sample by the laboratory authorized people. Then the dimensions specification and test frame selection has been completed and construction section has been designed according to the selected test frame. The designed test sample dimensions were 490 cm by 375 cm and the total height of the test slab was 34 cm. Top view and sections of the test slab is shown in Figure 4, Figure 5 and Figure 6.

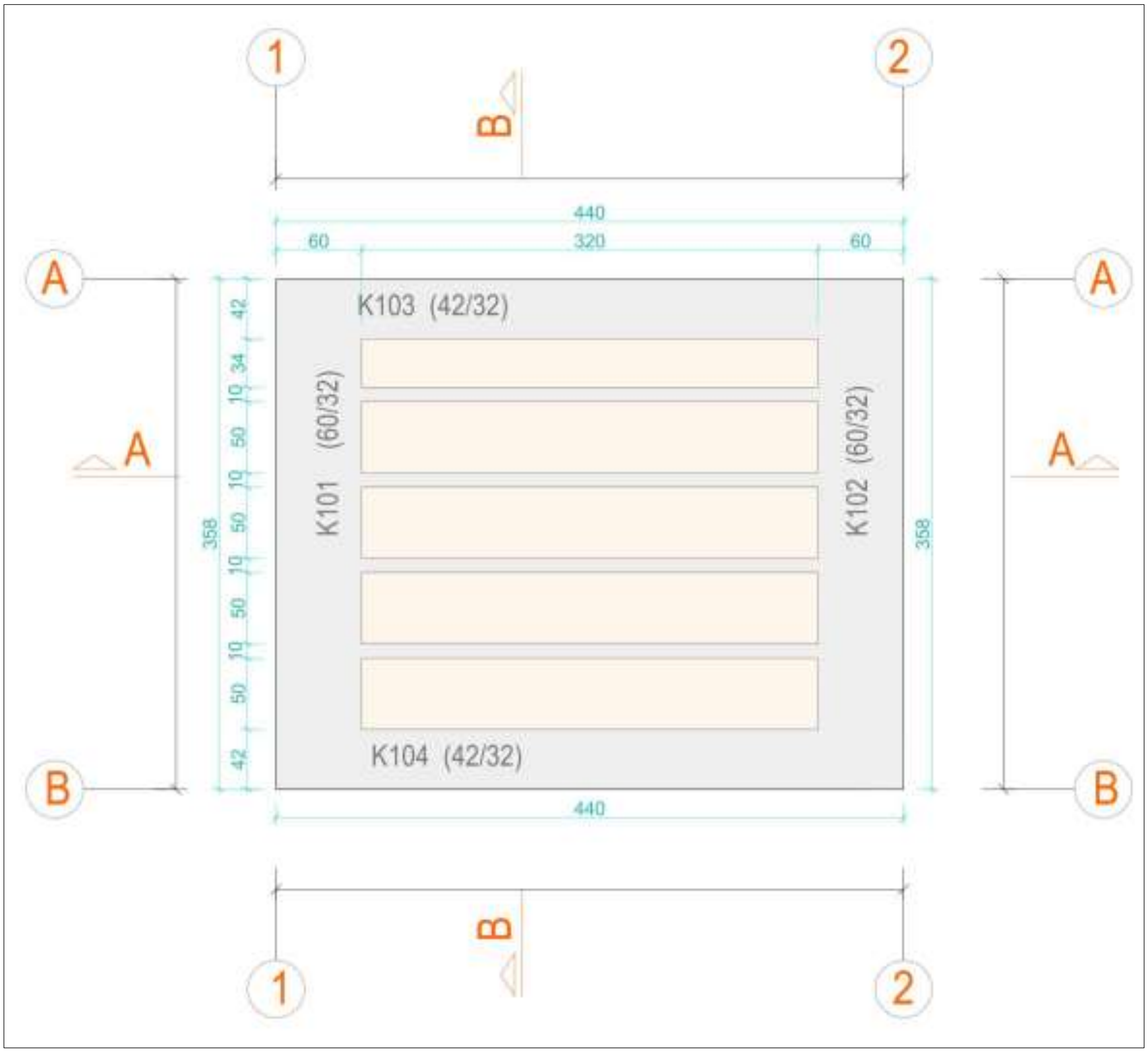


Figure 4. Top view of the sample one way hollow core slab system, not in scale

(by Erdemli)

Figure 5. Section A of the sample one way hollow core slab system, not in scale (by Erdemli)

Figure 6. Section B of the sample one way hollow core slab system, not in scale (by Erdemli)

The sample slab for the tests has been designed and calculated by a civil engineer and it is a kind of scaled sample of a real life building. During the construction period of the slab, firstly iron reinforcement has been constructed out of the frame suitable for dimensions of the frame. After that, whole test frame has been covered with thick plastic sheet to protect the frame from concrete, iron reinforcement and EPS16 filler with 25 cm height has been placed inside the frame. EPS fillers produced with 10 kg/m^3 and 16 kg/m^3 density were supplied by Basaş Packing and Insulation Industrial Company and they were produced from nonflammable raw material. This raw material is only usable for construction market for precautions against fire. The EPS fillers of 25cm x 50cm x 200cm. have been produced and transferred to test laboratory. The fillers cut according to given space on the technical project in laboratory and located among secondary girders of one way hollow core slab systems without any space between EPS blocks at short edges (See Figure 7, Figure 8 and Figure 9).

Figure 7. Reinforced concrete test frame and construction period (by Erdemli)

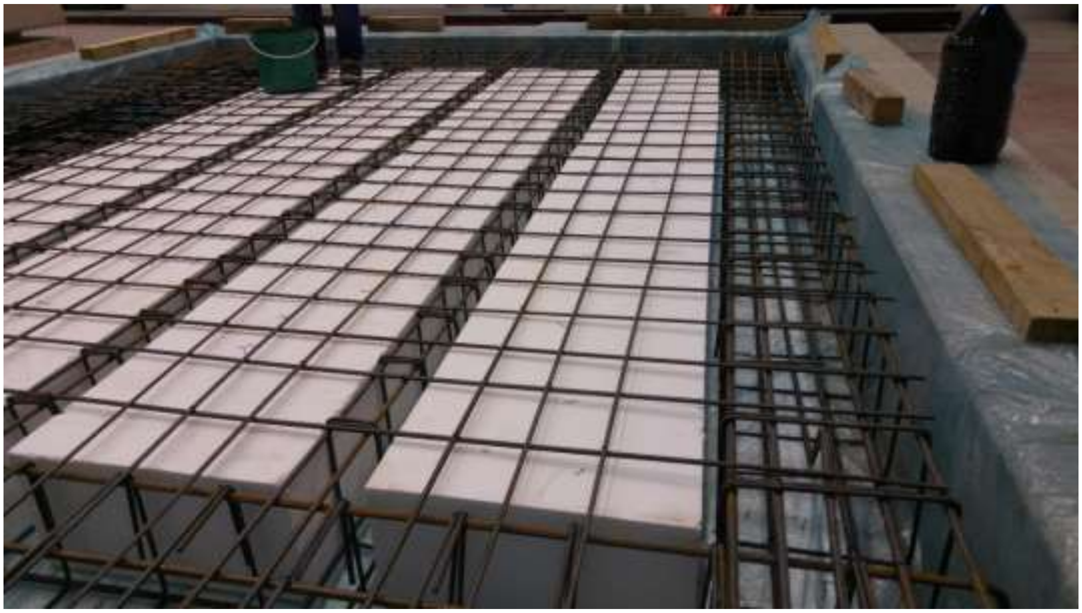


Figure 8. General view of the slab before application of concrete (by Erdemli)

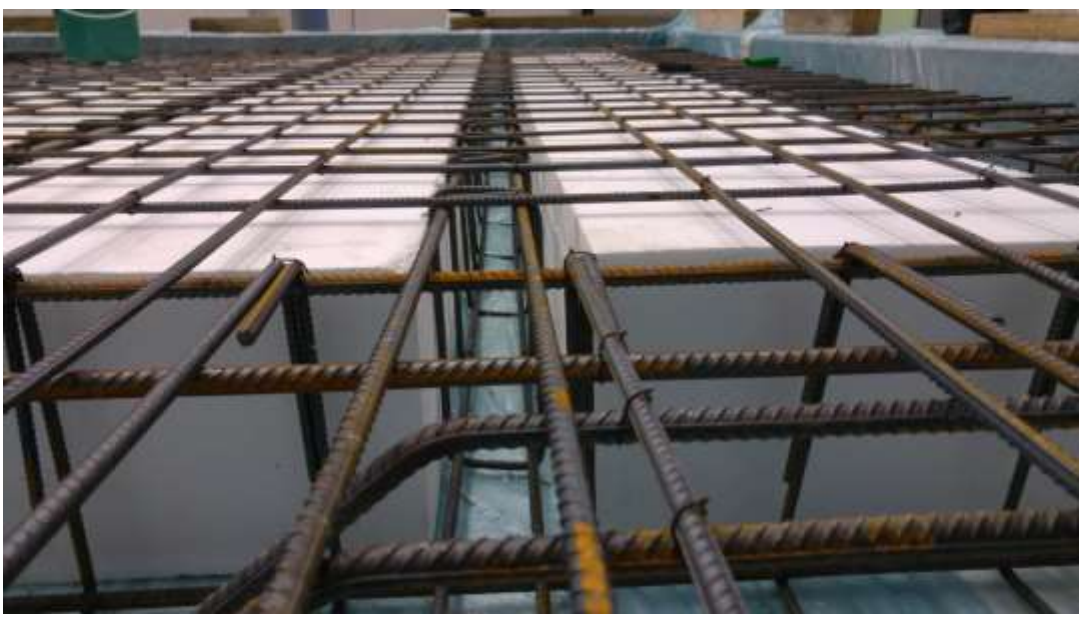


Figure 9. General view of iron reinforcement of girders and EPS block fillers (by Erdemli)

The test frame fulfilled up to 32 cm with the ordered C25 concrete selected as suitable concrete for the sample construction by civil engineer and ordered from İsmail Demirtaş Beton Plant. During the fulfillment of the frame the system prepared with 2 cm concrete cover around iron reinforcement (see Figure 10).

Figure 10. General view after concrete applied and finished sample slab without screed layer. (by Erdemli)

After fulfillment, the top surface of the slab has been smoothed for sensitive measurements. According to TS EN ISO 10140-3: 2011 and TS EN ISO 10140-4: 2011 requirements, the prepared slab has been left for stiffening for a period of 3 weeks. To determine impact sound insulation performance and effects of density differentiation, construction of two test slab which contain EPS fillers with different densities were needed however, high amount of tests and sample construction, only one slab was constructed and then EPS fillers were replaced before the second test (see Figure 11 and

Figure 12) As mentioned above, EPS16 was located during the construction of the slab due to the fact that stiffer structure of EPS16 can resist concrete load without squeezing. After the slab has been located in the test room and the first test has been performed on EPS 16 slab, the EPS16 fillers were taken out from the bottom of the slab via prepared scaffolding in the receiving room and EPS10 block fillers were fixed to space sensitively. Some little deformations occurred on EPS10 blocks because this material is very soft to use in construction and little fragmentations were observed during the process.

Figure 11 and Figure 12. EPS16 changes with EPS10 (by Erdemli)

There are two factors which should be considered to see limitations of the study. Firstly, as shown in Figure 9, all reinforced concrete slab has been covered with thin plastic covering as mentioned before to keep test frame sensitivity for the next laboratory tests. The effects of plastic covering on impact sound insulation eliminated while the tests were performing according to TS EN 10140-3: 2011. Secondly, after fulfilment of concrete and smoothing of the top surface, the slab was left for its first stiffening period and at the end of this period laboratory engineers noticed that the surface of the test sample should have 0, 2 cm sensitivity as highlighted in TS EN 10140-3: 2011 and TS EN 10140-4: 2013 at the top surface clearness for the best working condition of the tapping machine but the sample did not provide smooth surface for the tests as much as demanded (See Figure 9). In addition, according to our study design there will not be any extra layers at the top of the slab so as indicated by the laboratory engineers this situation will create a problem for the tapping machine to work sensitively. This point was important to get sensitive and healthy results. Therefore, to get smooth finishing layer, self-levelling screed were applied on top of the slab. Its thickness is changing on surface 0, 8 cm to 2 cm. For this reason, the test completed as thin self-levelling screed applied. This surprisingly formed layer is a possible layer for also in-suit applications to make the interior slab surface to application of any finishing layer like parquet or ceramic or using the surface without any extra finishing layer. Thus, the effect of this thin screed layer was also tested and recorded by this study.

3.3.2. The performed laboratory tests and techniques

TS EN ISO 10140 series involve laboratory measuring of acoustic insulation of construction elements. TS EN ISO 10140-3: 2011 involve general applications on any kind of pavement for impact sound insulation measuring in a laboratory which designed according to TS EN ISO 10140-5. Results of the tests may be used to compare and classify construction elements' sound insulation features and the design of construction materials which have specific acoustic features. The tests are also used to determine acoustic performance of built environment on site. The test can be applicable to any kind of heavy or light surface and surface coverings. However, the test method is only valid for laboratory measurements. The measurements have been performed in the test laboratory which has precautions about horizontal sound wave transmissions. During the TS EN ISO 10140-3:2011 tests, necessary precautions were taken to keep transmitted impact sound level minimum 10 dB; less than the sound produced from the source and spread into room through air (all leak around the test sample is included) for each frequency band. To get detailed information about the mentioned standards, look at Section 2.2.

TS EN ISO 10140-3: 2011 standard is using tapping machine impacts like the sounds that are caused from walking of a person who wears shoes, and the standards of the tapping machine is detected by TS EN ISO 10140-5 standard. In this test vertically located two room used for the tests and upper one is source room and lower one is receiving room (see Figure 13 and Figure 14). The tapping machine worked in source room and the microphones and speakers were located in receiving room. The interior of the receiving room shown in Figure 15 and 16. The analyzing room is working as a watching and analyzing the steps of the performed tests.

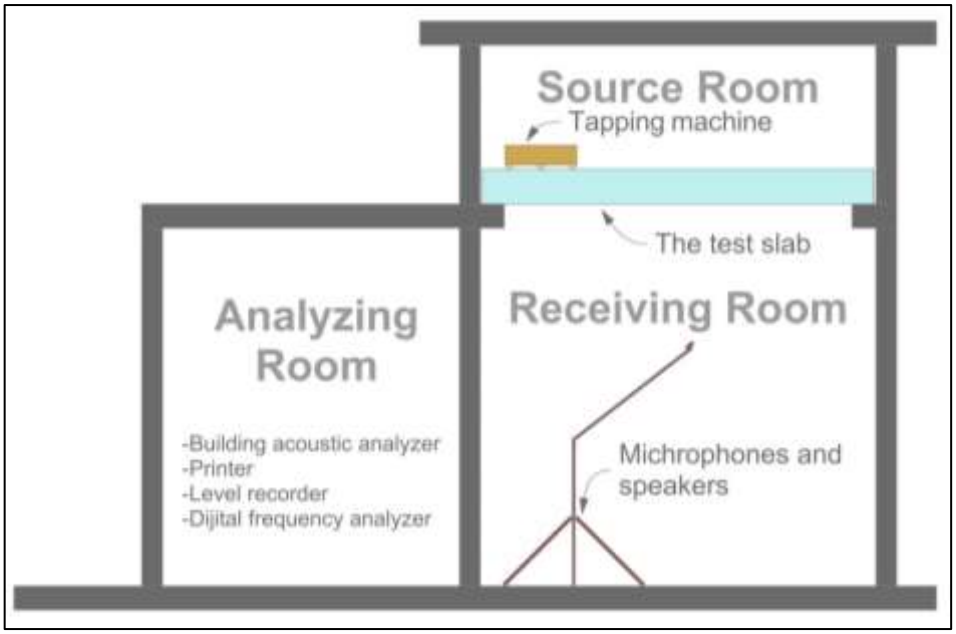


Figure 13. Sample drawing of laboratory test rooms (by Erdemli).

Figure 14. General view from outside of the test room (by Erdemli).

Figure 15. General view of the receiver room (by Erdemli).

Figure 16. General view of the receiver room (by Erdemli).

The test sample is dividing these two rooms and placed to the related opening constructed for the test frame (see Figure 17).

Figure 17. Opening of the laboratory test area to locate sample slab (by Erdemli)

According to the standards, the tapping machine impacts can be varied between low and high frequency like adult bare foot and child jumping and this situation is accepted as an alternative method for this test. The tapping source was located different points on the test sample and sound pressure levels in receiving room was measured between 100 Hz and 5000 Hz. Background noise and resonance period are calculated according to TS EN ISO 10140-4: 2013. According to the standard requirements, the tapping machine has to be located at minimum 4 different points on the sample and the distance between locations should be minimum 0, 7 m. Moreover, tapping machine has to be 0, 5 m far from the edges of the test sample. However, for the heavy homogenous samples like concrete based samples, tapping machine locations and directions on the sample have to be spread randomly. To get more effective and confidential results on non-homogenous samples like hollow core slabs or rough and irregular surface coverings, extra locations and directions have to be specified. As mentioned in the TSE Tuzla Acoustic Laboratory

Report, 60 second measurement period and 60 second for one full cycle was determined for mobile microphones. For each frequency band, six times measurement at two different source point, in total 12 measurement was completed. The resonance time was determined. L_n and L_{nw} value was determined by mentioned formulas in “Standards” section.

Tuzla Acoustic Laboratory used Norsonic Nor277 tapping machine, Gras Gras40AR ½ diffuse field microphone, Norsonic Nor1251 michrophone calibrator, Norsonic Nor280 power supplier for sound source and Norsonic Nor850-MFI ten-way sound level analyser for performing the tests.

TS EN ISO 717-2: 2013 – Acoustics. Rating of sound insulation in buildings and of building elements – Part 2: Impact sound insulation standard’s aim is to reach a single number value to state acoustic performance through gained impact sound insulation data depended on the frequency during TS EN ISO 10140-3: 2011 tests. At the end of the tests, laboratory submitted normalized impact sound pressure level (L_n) frequency and received dB graphic and the weighted normalized impact sound pressure level (L_{nw}) in the light of the TS EN ISO 717-2: 2013 standard. To see formulas and methods of the calculations see Section 2.2.

CHAPTER IV

RESULTS

4.1. Findings about the performed tests on EPS 10 and EPS 16

The stated test report by TSE Tuzla Acoustic Laboratory, EPS10 and EPS16 demonstrated varied performance to reduce impact sound pressure level on the slab. The conditions of the test area during the EPS10 test was indicated like that the receiver room has 174, 4 m^3 and the source room has 114, 9 m^3 interior space; the temperature was 23, 9 ^{0}C in receiving room and 24, 4 ^{0}C in source room; relative humidity was 81, 4 % in receiving room an 80,3 % in source room and statistical pressure was 100, 6 kPa. The received standard deviation was 31, 7 dB for EPS10, as stated in the test report. The performed test on EPS10 sample demonstrate increasing graphic until 800 Hz. However, during this period two times standard deviation has been monitored at low frequencies between 50 Hz and 250 Hz and the mid frequencies between 800 Hz and 1000 Hz (see Figure 18). The normalized impact sound pressure level performed parallel to ISO 717-2:2013 reference curve between 630 Hz and 1000 Hz frequency, but between 630-800 Hz, impact sound reduction increased significantly when compared with the rest of the graphic (see Figure 18). By 800 Hz, EPS10 reached its peak point of normalized impact sound pressure level reduction (see Figure 18). The received impact sound pressure level of the EPS10 decrease after 1600 Hz, similar to the reference curve of ISO 717-2:2013 but in wide frequency range (see Figure 17). The submitted L_{nw} (C_1) = 80, 3 dB and the relevant spectrum adaptation term for tapping machine is $C_{1,\ 150\text{-}2500}$ = -10

Figure 18. The normalized impact sound pressure levels (L_n) according to frequencies in receiving room for EPS10 (Appendix A).

The stated report by TSE Tuzla Acoustic Laboratory, the EPS16 sample laboratory test performed under these conditions; the receiver room is 174, 4 m^3 and the source room is 114, 9 m^3 , the temperature was 23, 6 ^{0}C in receiving room and 24, 4 ^{0}C in source room; relative humidity was 79, 5 % in receiving room and 80, 3 % in source room, and statistical pressure was 100, 2 kPa. The received standard deviation was 28, 8 dB for EPS16 according to the submitted report by Tuzla Acoustic Laboratory. EPS16 demonstrated more stable increasing than EPS10 without any standard deviation from 50 Hz to till 800 Hz. The normalized impact sound pressure level decreased especially between 80-100 Hz and 160-250 Hz ranges (see Figure 19). Impact sound pressure level increased significantly between 400-800 Hz (see Figure 19). Similar to the EPS10, EPS16 also demonstrated high ratio standard deviation between 50-800 Hz ranges (see Figure 19). Between 800-1250 Hz ranges, normalized impact sound pressure level decreased like reference curve of ISO 717-2:2013. Nevertheless, between 1250-1600 Hz ranges, the normalized impact sound pressure level again increased during EPS16 tests (see Figure 19). Then, similar to the reference curve, the pressure level began to decreasing by 1600 Hz but in a wider frequency range than the reference curve (see Figure 19). The submitted L_{nw} ($C_{1,}$) = 92 dB and the relevant spectrum adaptation term for tapping machine is $C_{1,\ 150\text{-}2500}$ = -11

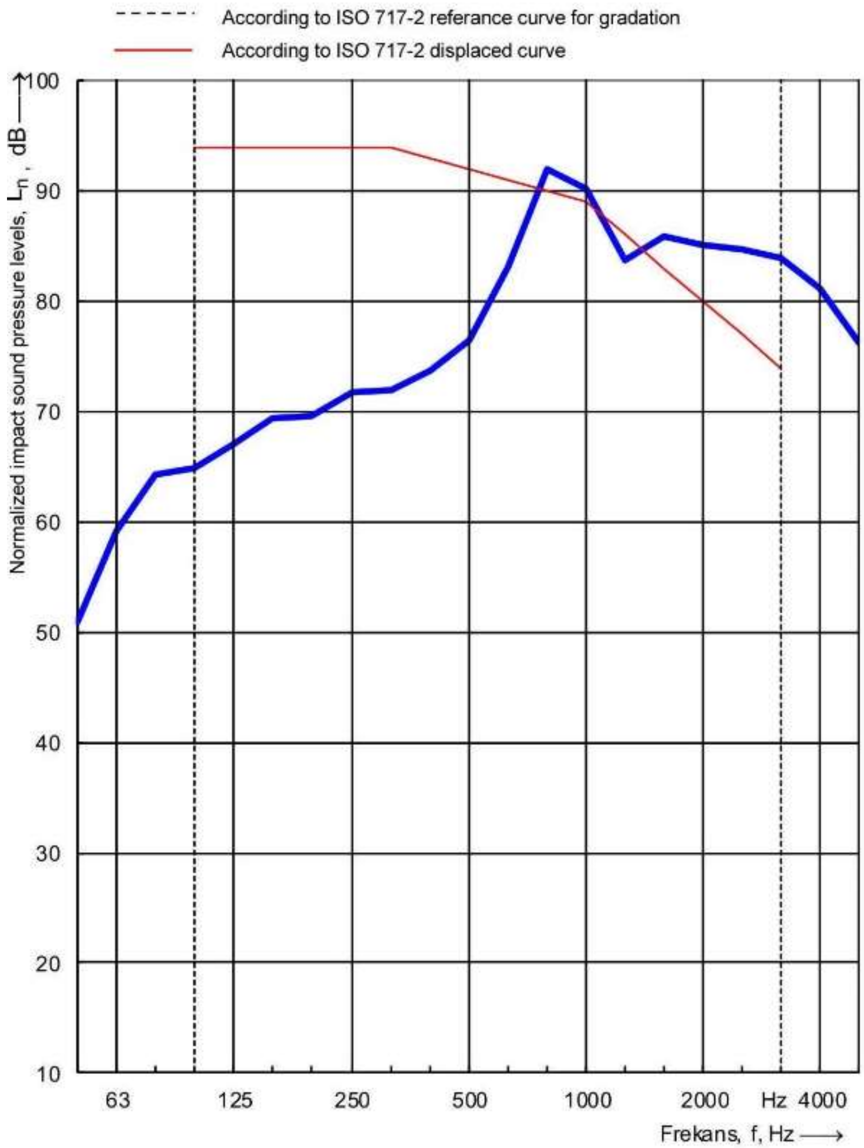


Figure 19. The normalized impact sound pressure levels (L_n) according to frequencies in receiving room for EPS16 (Appendix B).

The exact locations of the taping machine in source room during the tests showed in Figure 20 and locations of speakers and microphones showed in Figure 21. These locations of tapping machine, speakers and microphones were same during the test of EPS10 and EPS16.

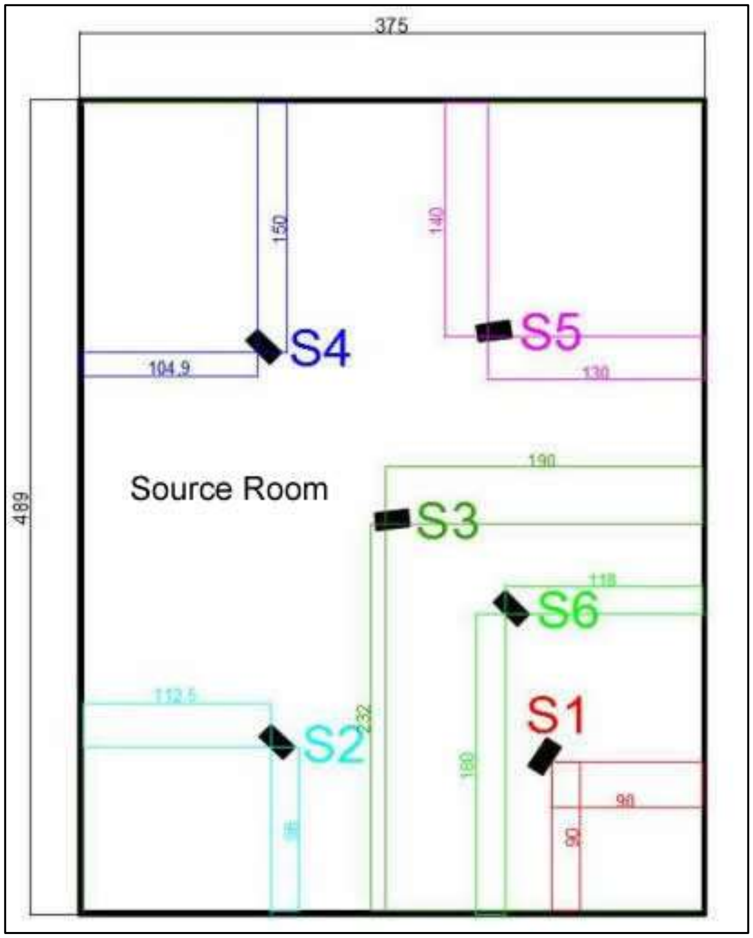


Figure 20. Top view of the tapping machine locations in the source room

(Figure from TSE Tuzla Acoustic Laboratory Test Report for Eray Erdemli)

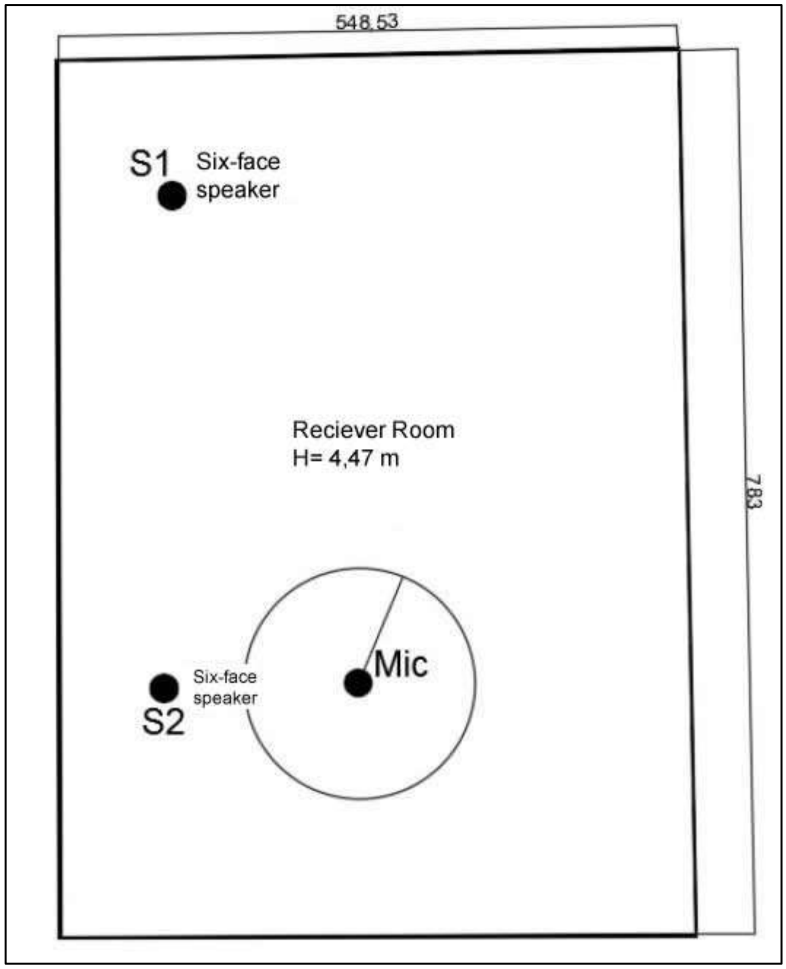


Figure 21. Top view of the speaker and microphone location in the receiver room (Figure from TSE Tuzla Acoustic Laboratory Test Report for Eray Erdemli)

One of the significant parameter for determining standard deviation is repeater measurements to control verification and validation of the results on the same points of the tapping machine. However, Tuzla Acoustic Laboratory orally mentioned that they performed the repeater measurements to control the results, but they did not submit the results of the repeater measurements on the same points of the tapping machine though the results were requested.

4.2. Discussion

4.2.1. Normalized Impact Sound Pressure Level Evaluation According to Frequency Ranges

The tests performed on EPS10 and EPS16 demonstrated performance variety according to frequency ranges. The transmitted impact sound pressure level values of the EPS10 sample were low at low and mid frequencies more than high frequencies (see Table 7). The normalized impact sound pressure level of the EPS10 between 80 Hz and 100 Hz demonstrated significant decreasing. However, just before this diffraction, the impact sound pressure level increased significantly until 80 Hz (see Table 7). It reached peak point of normalized impact sound pressure level by 77, 5 dB in 1/3 octave band at 800 Hz and it was closest point with the reference curve of the ISO 717-2:2013 (see Table 6). The normalized impact sound pressure level curve and the reference curve of the EPS10 clashed at 1250 Hz with the impact sound pressure level 75, 4 dB (see Table 7). By 1600 Hz, the EPS10 demonstrated decreasing of impact sound insulation performance at high frequencies. The submitted test report by TSE Tuzla Acoustic Laboratory for the EPS10 demonstrate the weighted normalized impact sound pressure level in the receiving room L_{nw} (C_1) $=$ 80, 3 dB, $C_{1,150\text{-}2500}$= -10 according to TS EN ISO 717-2: 2013. When compared with the given data in literature review by the Cost Action TU 0901 project; most of participators of the project such as Germany, Austria and Lithuania demanded weighted normalized transmitted impact sound level $L_{nw} \leq 53$ dB according to ISO 717-2: 2013 (Cost Action TU 0901, 2014). Besides, the obtained result on one way hollow core slab with EPS10 filler demonstrated poor performance than the declared the poorest value weighted normalized impact sound of the Italy by $L_{nw} \leq 63$ dB in the study Cost Action TU 0901 (2014). Therefore the EPS10 is not effective performance to limit transmitted impact sound pressure level as much as demanded. Moreover, the given normalized impact sound pressure level (Ln) values in Cost Action TU 0901 did not show variation according to types of slabs. Nevertheless, specializing according to types of dwelling slabs may be more efficient to rating impact sound insulation of slabs.

The received standard deviation was 28, 8 dB for EPS16 and 31, 7 dB for EPS10, as stated in the test report submitted by Tuzla Acoustic Laboratory. These value demonstrated that standard deviation quantities were significantly high for the slabs. High amount of standard deviation also demonstrated significant differences on received sound of receiving room microphones. Therefore, non-homogenous structure of the preferred slab system, sound bridges through secondary girders or flanking noise may be caused to increase of standard deviation values. Moreover, one of the significant parameter for determining standard deviation is repeater measurements to control verification and validation of the results on the same points of the tapping machine, but, Tuzla Acoustic Laboratory did not submit the results of the repeater measurements on the same points of the tapping machine though the results were requested to analyze what cause such a big value standard deviations.

EPS16 in construction market was accepted more sufficient material for the impact sound insulation. This situation was a kind of universal consent in Turkey. Similar to the EPS10, the EPS16 demonstrated better performance at low and mid frequencies. Nevertheless, the EPS16 demonstrated poorer performance at high frequencies than the EPS10 and expectations from this study were that the EPS16 performance at low and mid frequencies could be close and similar to the reference curve (see Table 7). The EPS16 reached peak normalized impact sound pressure level value by 92 dB in 1/3 octave band at 800 Hz (see Table 7). The peak value frequencies of the ESP16 and the EPS10 were same. The impact sound pressure level performance decreased after 800 Hz. Nonetheless, it had significantly considerable diffraction between 1250 Hz and 1600 Hz and impact sound pressure level increased 2 dB between the given frequency ranges. This diffraction occurred also on the EPS10 between 1000 Hz and 1600 Hz and the pressure level increased 1.4 dB between these ranges. The EPS16 test report stated by Tuzla Acoustic Laboratory says that weighted normalized impact sound pressure level was L_{nw} (C_1) = 92 dB, and $C_{1,150\text{-}2500}$= -11 according to ISO 717-2:2013. This results demonstrated that EPS10 more sufficient than the EPS16. In addition, EPS16 is also does not adequate to accepted impact sound insulation values by many participator countries of the Cost Action TU0901 project. Even Italy with $L_{nw} \leq 63$ dB is much better than the received results from the laboratory results of the EPS16. The study also aimed to enhancement in production and construction quality by cost effectiveness, therefore preferring the EPS16 is not suitable because of poor impact sound insulation and high costs with %50 higher value than the EPS10. Moreover, the EPS16 is heavier than the EPS10 and usage of it increase the dead load per a square meter of the one way hollow core slab. This point is also affect negatively construction quality of a structure. Therefore, the EPS16 is not efficient when evaluated in all its parts.

The second hypothesis of this study was “The weighted normalized impact sound pressure level (L_{nw}) of one way hollow core slabs with EPS filler has lower performance than given values in the literature”. The results of the performed tests on the one way hollow core slab system with the EPS16 and the EPS10 filler demonstrate poor performance than the participator of the Cost Action TU0901 countries with the weighted normalized impact sound pressure. Most of daily activities such as footsteps, sound produced by equipment in dwelling and playing children cause noise at mid and high frequency range (Cost Action TU 0901, 2014). In addition, the samples demonstrated poor performance at mid and high frequencies so they could not create acoustically comfortable interiors for dwellings where many daily activities was performed. Therefore, the second hypothesis may be confirmed. Nevertheless, the EPS16 showed better performance than the EPS10 at specific low frequencies, 2, 8 dB in 50 Hz, 0, 44 in 63 Hz and 0, 9 in 80 Hz. The similar unexpected fraction observed at 315 Hz with 0, 1 dB difference but it was so low value difference and it doesn’t have any significant effect on the performance of the slabs.

Table 7. Reference values for impact sound in 1/3 octave band for EPS10 (Appendices A and Appendices B)

Frequency F (HZ)	**L_n EPS10 1/3 octave band (dB)**	**L_n EPS16 1/3 octave band dB)**
50	53,8	51,0
63	60,3	59,2
80	65,2	64,3
100	63,3	64,8
125	66,9	671
160	68,6	69,4
200	69,2	69,6
250	71,3	71,7
315	72,1	72,0
400	72,3	73,8
500	72,3	76,4
630	74,8	83,2
800	77,5	92,0
1000	74,6	90,3
1250	75,4	83,8
1600	76,0	85,8
2000	74,7	85,1
2500	74,2	84,7
3150	72,9	83,9
4000	70,7	81,1
5000	66,6	76,2

The study of Park, Kim Oh and Cho (2016) on compressively deformed graphite embedded EPS highlighted that impact sound insulation demonstrated efficiently improvement above 60 Hz by this. Therefore, the results showed that the EPS fillers have tendency to reduce impact sound pressure which occurred in low and mid frequencies. However, modification on the production process and material usage is necessary to increase impact sound insulation performance.

The one way hollow core slab which is commonly preferred construction type in Turkey. Nevertheless, it did not compensate the demand of Cost TU 0901 countries about impact sound insulation in dwellings. The constructed sample one way hollow core slab with EPS16 and EPS10 filler designed without resilient layers to keep minimum construction investment in real life. In addition, the samples did not have any finishing layer like ceramic or parquet to see performance of the one way hollow core slab without any enhancement layer. For the further researches, the slabs with resilient and finishing layers can demonstrate better performance than the tested ones. This kind of study also open to determine performance difference or resilient layers effects on enhancement ratio of impact sound insulation on one way hollow core slabs. One way hollow core slab systems commonly built and keep building in some regions with traditional brick fillers before spread of EPS production in Turkey. Therefore, to compare and evaluate traditional brick and EPS fillers impact sound insulation performance one way hollow core slab with traditional brick fillers may also subjected to TS EN ISO 10140-3:2011 laboratory tests. This kind of study also limit the existing dilemmas in construction material market about usage of these two materials.

4.2.2. Comparison of Density Difference

As stated previous sections, the occupants who live in buildings constructed with EPS10, complained about the poor performance of EPS10 impact sound insulation. Many times, EPS16 is marketing as more effective material than EPS10 to minimize impact sound pressure material so one of the hypothesis was conducted on "if the density of the expanded polystyrene block fillers is increased, impact sound insulation performance increases"**.** The received data demonstrated that when density increased, there is not significant difference occurs at low and mid frequencies normalized impact sound pressure level. Nevertheless, especially EPS16 at high frequencies, the normalized impact sound pressure level received in the receiving room increased significantly. In addition, insufficient performance of EPS10 at low frequencies was an expected result in the light of occupant feedbacks. EPS16 is stiffer material than the EPS10 so the results received from the performed tests in acoustic laboratory espoused the information declared by the Eumeps Whitebook (2016). The Eumeps White Book (2016) says that low value of dynamic stiffness (density, hardness) lead to decrease received impact sound pressure level so low density EPS filler preferred one way hollow core slab is more efficient to minimize received impact sound pressure. On the other hand, EPS10 demonstrated expectedly better performance at low frequencies due to low stiffness effect, but low performance of EPS16 at high frequencies could not be clarified. Especially at mid and high frequencies, the stiff structure of the EPS16 cause diffraction and impact sound pressure increased significantly after 400 Hz. However, EPS10 did not reach optimum reduction of impact sound pressure values like the EPS16 in the same frequency ranges. Besides, the study stated by Branco and Godinho (2013), Park, Kim

Oh and Cho (2016) and Maderuelo-Sanz, Martín-Castizo, Vílchez-Gómez (2011) said that when the stiffness increased on the slab, impact sound reduction was decreasing significantly so stiffness is an important factor for the controlling impact sound pressure level on slab systems. This statement was proven one more time with these laboratory tests. Therefore, the hypothesis “if the density of the expanded polystyrene block fillers is increased, impact sound insulation performance increases” may be failed.

Technically, EPS10 is not so suitable material for construction market because of its weak structure against dead load of concrete and crumbling during construction. However, it is going to be more sufficient material thanks to its low density structure to reduce impact sound pressure on one way hollow core slab systems.

CHAPTER V

CONCLUSION

This thesis presents a study of detecting impact sound insulation performance of one way hollow core slab with 10 kg/m^3 and 16 kg/m^3 EPS block fillers at 1/3 octave band and also gave answer to investigate density differences effects of EPS block fillers on normalized impact sound pressure levels. The study aimed enhancement in production of EPS materials for using sound insulation purpose, improving quality of multistory dwellings construction and highlighting missing standards and regulations about sound insulation in dwellings in Turkey to increase interior acoustic comfort.

Its contribution lies on that normalized impact sound pressure levels of one way hollow core slab system measured at the first time through two different expanded polystyrene; EPS10 and EPS16. The one way hollow core slab system and effects of density differences determined through laboratory tests in TSE Tuzla Acoustic Laboratory. Even though, normalized impact sound insulation values of EPS10 and EPS16 was so close to each other, EPS10 demonstrated better normalized impact sound insulation performance than EPS16. Therefore, one of the hypothesis conducted on “If the density of the expanded polystyrene block fillers is increased, impact sound insulation performance increases" and it may be failed. However, when EPS16 and EPS10 were compared, EPS10 demonstrated expectedly better performance at low frequencies due to low stiffness effect, but low performance of EPS16 at high frequencies could not be clarified. Literature review has given us the opportunity to see that stiffness is significant factor for decreasing impact sound insulation especially at mid and high frequencies so EPS16 with its stiffer structure demonstrated poor performance against impact sound pressure. Moreover, the performed laboratory tests showed that one way hollow core slab system with EPS10 and EPS16 fillers could not respond needs of multi storey dwellings weighted normalized impact sound insulation (L_{nw}) values accepted by participator countries of Cost Action TU 0901. Thus, the second hypothesis conducted on 'The weighted normalized impact sound pressure level (L_{nw}) of one way hollow core slabs with EPS filler is lower than the given values in the literature' may be confirmed. The given normalized impact sound pressure level (L_{nw}) values in Cost Action TU 0901 did not show variations according to types of slabs, but one way hollow core slab with EPS filler has layers in its own structure so it is a kind of non-homogenous slab system. Therefore, specializing according to types of dwelling slabs may be more efficient to rating impact sound insulation of slabs.

The received standard deviation was 28, 8 dB for EPS16 and 31, 7 dB for EPS10, according to the submitted results of Tuzla Acoustic Laboratory. These values demonstrated that standard deviation quantities were significantly high for the slabs. In addition, this high amount of standard deviations stated significant differences on received sound of receiving room microphones. Thus, non-homogenous structure of the preferred slab system, sound bridges through secondary girders or flanking noise may be caused to increase of standard deviation values. Tuzla Acoustic Laboratory did not submit repeater measurements on the same points of the tapping machine to control verification and validation of the results as a significant parameter for determining standard deviation, although the results were requested to control how such a big standard deviations received at the end of the tests.

This current study not only determine one way hollow core slab with EPS fillers and effects of used EPS fillers' density on normalized impact sound insulation, but also highlighted missing regulations and standards about building acoustics through impact sound insulation as one of most problematic topic of building stock in Turkey. The received results lead to specify values for governmental regulations and standards to build dwellings with acoustically comfortable. The EPS fillers are very common filler material for one way hollow core slab system in Turkey. Nonetheless, as presented in literature review, there is not any study available to analyze EPS materials in terms of impact sound insulation to use in one way hollow core slab sufficiently. The obtained results and comparisons will help to enhance production of EPS materials to use in one way hollow core slabs effectively or lead to selection of appropriate material in one way hollow core slabs to maximize impact sound insulation.

For further researches, two different one way hollow core slab can be constructed to reduce the crushing effect of changed fillers. After construction EPS16, fillers crushed and shrank under concrete dead load. Therefore, during the changing filler materials, the new ones leant bottom of girders around 1 cm. However, this situation did not took into account though the thickness of the filler material changed and the thickness is important factor for impact sound insulation. In addition, while EPS10 was changing with EPS16, EPS10 was deformed because of so soft structure of EPS beams but this deformations did not take into account. In addition, the restricted budget of the study limited performing tests with higher density EPS fillers to analyze their impact sound insulation. Besides, airborne sound insulation tests can be performed on the prepared test samples to determine also airborne sound insulation performance of the slabs and analyze EPS as a construction material to enhance acoustic comfort of interiors more efficiently. Moreover, to study effects of the layers on one way hollow core slab in terms of impact sound insulation, resilient layers and finishing layers can be applied on the slabs and perform the laboratory tests with these layers. This could be good to see impact sound insulation performance of the slab systems by analyzing system with different perspectives.

As stated in the test report by Tuzla Acoustic Laboratory, rating of the slab was obtained by preferred software according to TS EN ISO 717-2:2013 in the laboratory, but the software may not be suitable to demonstrate non-homogenous slab behaviors clearly like one way hollow core slab with EPS filler. In addition, TS EN ISO 717-2: 2013 has adjustment coefficient value for hollow core slab systems. Nevertheless, the submitted test reports by Tuzla Acoustic Laboratory did not clearly mentioned whether the software took into account this values or not. In addition, the submitted normalized impact sound pressure level (L_{nw}) graphic of EPS10 and EPS16 by Tuzla Acoustic

Laboratory was in JPEG format so the graphics could not match with each other clearly. However, if a new graphic designed in a software according to values submitted in Table 7, results will be stated in graphic more comprehensibly.

Moreover, analyze and determine acoustical performance of one way hollow core slabs with EPS fillers and EPS fillers in detail, the tests can be performed on one way hollow core slab with traditional brick fillers so efficient comparison with traditional filler and the EPS filler can be determined clearly. Finally, to get more realistic results and create a calculation model for analyzing non-homogenous slabs without laboratory tests can be useful. This kind of calculation model can be improved by impact sound pressure level measurements performed with full-scale building sample which used EPS10 and EPS16 in one way hollow core slab system and obtaining results with the available laboratory data.

BIBLIOGRAPHY

Agoua, E., Allognon-Houessou, E., Adjovi, E., & Togbedji, B., 2013. Thermal conductivity of composites made of wastes of wood and expanded polystyrene. *Construction and Building Materials*, 41, 557-562.

Branco, F. G., & Godinho, L., 2013. On the use of lightweight mortars for the minimization of impact sound transmission. *Construction and Building Materials*, 45, 184-191.

Demirboga, R., & Kan, A., 2012. Thermal conductivity and shrinkage properties of modified waste polystyrene aggregate concretes. *Construction and Building Materials*, 35, 730-734.

Egan, D., M., 2000. *Architectural Acoustics Workbook.* Massachusetts: The Robert Bradford Newman Student Award Fund.

Egan, M. D. (2007). *Architectural acoustics.* J. Ross Publishing Classics

EPS Industry Alliance, 2016. Retrieved March 3, 2016 from URL: http://www.epsindustry.org/building-construction/sound-transmission

European Manufacturers of Expanded Polystyrene (EUMEPS), 2016. Retrieved March 3, 2016 from URL: http://www.eumeps.construction/

European Manufacturers of Expanded Polystyrene (EUMEPS), 2016. *EPS White Book, Background Information on Standardization of EPS*. Retrieved from URL: http://www.eumeps.org.

Ferrándiz-Mas, V., & García-Alcocel, E., 2013. Durability of expanded polystyrene mortars. *Construction and Building Materials*, 46, 175-182.

Florea, V., 2012. External Thermal Insulation of Buildings with Expanded Polystyrene. *Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura*, 58(3), 45.

Ineos Styrenics, 2015. User Guidance to use of expandable polystyrene foam for airborne sound insulation applications, Ineos Styrenics Headquarter.

Standard TS EN I.S.O., 2013. 717-2. Acoustics. Rating of sound insulation in buildings and of building elements – Part 2: Impact sound insulation. *Turkish Standard Institute, International Organization for Standardization.*

Standard TS EN I.S.O., 2011. 10140-3.Acoustics. Laboratory measurements of sound insulation of building elements- Part 3: Measurement of impact sound insulation. *Turkish Standard Institute, International Organization for Standardization.*

Standard TS EN I.S.O., 2013. 10140-4. Acoustics. Laboratory measurements of sound insulation of building elements- Part 4: Measurement procedures and requirements. *Turkish Standard Institute, International Organization for Standardization.*

Standard TS EN I.S.O., 2013. 10140-5. Acoustics. Laboratory measurements of sound insulation of building elements- Part 5: Requirements for the test facilities and equipment. *Turkish Standard Institute, International Organization for Standardization.*

Kim Kyoung-Woo, Jeong Gab-Cheol, Yang Kwan-Seop, Sohn Jang-yeul, 2009. Correlation between dynamic stiffness of resilient materials and heavyweight impact sound reduction level. *Building and Environment,* 44, 1589–1600.

Maderuelo-Sanz, R., Martín-Castizo, M., & Vílchez-Gómez, R., 2011. The performance of resilient layers made from recycled rubber fluff for impact noise reduction. *Applied Acoustics*, 72(11), 823-828.

Mıhlayanlar, E., Dilmaç, Ş. Güner, A., 2007. Analysis of the effect of production process parameters and density of expanded polystyrene insulation boards on mechanical properties and thermal conductivity. *Material and Design,* 29, 344-352

Najim KB, Hall MR., 2012. Mechanical and dynamic properties of self-compacting crumb rubber modified concrete. *Construct Build Mater,* 27, 521–530.

Park, H. S., Kim, Y., Oh, B. K., & Cho, T., 2016. Compressive properties of graphite-embedded expanded polystyrene for vibroacoustic engineering applications. *Composites Part B: Engineering*, 93, 252-264.

Stewart, M. A., & Craik, R. J., 2000. Impact sound transmission through a floating floor on a concrete slab. *Applied Acoustics*, 59(4), 353-372.

Uzun, İ., Unal, P., 2016. Isıl İletkenliğin Farklı Yoğunluktaki EPS Ürünler için Değişimi. Retrieved March 3, 2016 from URL: http://epsder.org.tr/dokumantasyon.html

Yucel, K. T., Basyigit, C., & Ozel, C. 2003. Thermal insulation properties of expanded polystyrene as construction and insulating materials. *In15th Symposium in Thermophysical Properties* (pp. 54-66).

APPENDICES

APPENDIX A

TS EN ISO 10140-3 STANDARDINA GÖRE DARBE SES BASINÇ SEVİYESİ AZALTIMI

Döşeme darbe sesi yalıtımı laboratuvar ölçümleri

Müşteri: Güçsan 1 Otomotiv Endüstriyel Makinaları Üretimi İth. İhr. Sa Date of test: 30.06.2016

Üretici:

Deney odalarının tanıtımı: Üst kısımdaki hareketli oda kaynak oda, alt kısımdaki sabit oda alıcı oda olmak üzere düşeyde iki deney odası bulunmaktadır.Kaynak oda 74,1 m3 alıcı oda ise 174,4 m3 hacme sahiptir.Alıcı odada ses dağınıklığını sağlamak amacıyla saçıcı paneller kullanılmıştır.

Deney numunesi müşteri tarfından referans deney çerçevesine yerleştirilmiştir.

Numunenin tanımlanması: Asmolen Tip 2 – 10kg/m3 yoğunluklu EPS asmolen bloklarla oluşturulmuş, 25cm diş derinliği 7 cm plak kalınlığı olan, en üst tabakasına yaklaşık 2cm kalınlığında Hammerfast Marka yüzey düzleştirici uygulanan tek doğrultulu dişli döşeme

Alıcı Oda

Hacim: 174,4 m³

Hava sıcaklığı: 23,9 °C

Bağıl nem: 81,4 %

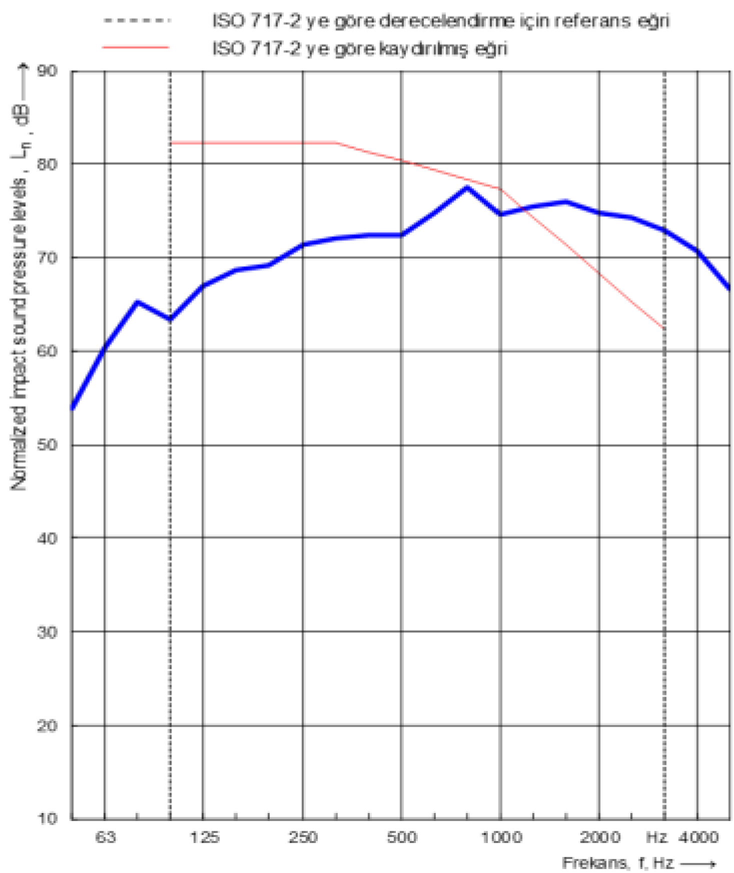
Statik basınç: 100,6 kPa

Kaynak oda:

Hacim: 74,1 m³

Kür süresi: 28 gün

Frekans f [Hz]	L_n 1/3 oktav [dB]
50	53,8
63	60,3
80	65,2
100	63,3
125	66,9
160	68,6
200	69,2
250	71,3
315	72,1
400	72,3
500	72,3
630	74,8
800	77,5
1000	74,6
1250	75,4
1600	76,0
2000	74,7
2500	74,2
3150	72,9
4000	70,7
5000	66,6



ISO 717-2 ye göre derecelendirme

$L_{nw}(C_I)$ = 80,3 (-10) dB

$C_{I50-2500}$ = -10 dB

Sonuçlar, laboratuvar koşulları altında yapay kaynakla gerçekleştirilen bir deneye dayanır.(Mühendislik met)

APPENDIX B

TS EN ISO 10140-3 STANDARDINA GÖRE DARBE SES BASINÇ SEVİYESİ AZALTIMI

Döşeme darbe sesi yalıtımı laboratuvar ölçümleri

Müşteri: Güçsan 1 Otomotiv Endüstriyel Makinaları Üretimi İth. İhr. San. ve Tic. A.Ş.

Deney tarihi: 27.06.2016

Deney odalarının tanıtımı: Üst kısımdaki hareketli oda kaynak oda, alt kısımdaki sabit oda alıcı oda olmak üzere düşeyde iki deney odası bulunmaktadır.Kaynak oda 74,1 m3 alıcı oda ise 174,4 m3 hacme sahiptir.Alıcı odada ses dağınıklığını sağlamak amacıyla saçıcı paneller kullanılmıştır.

Deney numunesi müşteri tarfından referans deney çerçevesine yerleştirilmiştir.

Numunenin tanımlanması: Asmolen Tip 1 – 16kg/m3 yoğunluklu EPS asmolen bloklarla oluşturulmuş, 25cm diş derinliği 7 cm plak kalınlığı olan, en üst tabakasına yaklaşık 2cm kalınlığında Hammerfast Marka yüzey düzleştirici uygulanan tek doğrultulu dişli döşeme

Alıcı Oda

Hacim: 174,4 m³

Hava sıcaklığı: 23,6 °C

Bağıl nem: 79,5 %

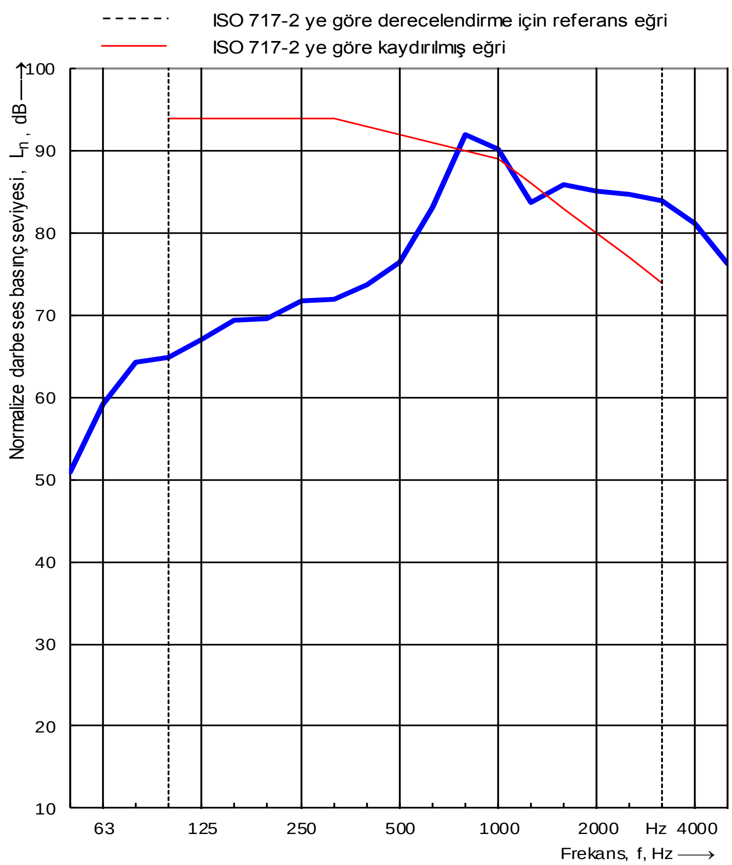
Statik basınç: 100,2 kPa

Kaynak oda:

Hacim: 114,9 m³

Kür süresi: 28gün

Frekans f [Hz]	L_n 1/3 oktav [dB]
50	51,0
63	59,2
80	64,3
100	64,8
125	67,1
160	69,4
200	69,6
250	71,7
315	72,0
400	73,8
500	76,4
630	83,2
800	92,0
1000	90,3
1250	83,8
1600	85,8
2000	85,1
2500	84,7
3150	83,9
4000	81,1
5000	76,2



ISO 717-2 ye göre derecelendirme

$L_{nw}(C_I)$ = 92 (-11) dB

$C_{I50\text{-}2500}$ = -11 dB

Sonuçlar, laboratuvar koşulları altında yapay kaynakla gerçekleştirilen bir deneye dayanır.(Mühendislik met)