SELÇUK ÜNİVERSİTESİ
MÜHENDİSLİK FAKÜLTESİ

S.Ü. Müh. Bilim ve Tekn. Derg., c.6, s.3, ss. 461-477, 2018
Selcuk Univ. J. Eng. Sci. Tech., v.6, n.3, pp. 461-477, 2018
ISSN: 2147-9364 (Electronic)
DOI: 10.15317/Scitech.2018.145

DETERMINATION OF SOUND TRANSMISSION LOSS IN LIGHTWEIGHT CONCRETE WALLS AND MODELING ARTIFICIAL NEURAL NETWORK

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(Geliş/Received: 24.10.2017; Kabul/Accepted in Revised Form: 24.12.2017)

ABSTRACT: In this paper, analysis of sound transmission losses through lightweight concrete walls was conducted against the high way trafic noises. The walls are generally used for thermal insulation purposes in Turkey. Sound transmission was modeled using ANN. Input parameters frequency, density of lightweight concrete wall and thickness of lightweight concrete wall structure (f, M, $d_{2)}$ and output parameter TS were described.

When the outcomes of the TS analysis and those of ANN modeling are summarized together; Sound transmission losses improve with higher frequencies, higher wall densities and increased wall cross sections. Regardless of sufficient thermal insulation of single layered lightweight concrete walls as stipulated by the Turkey Institute of Standards (TSE 825), the wall cross sections were found to be insufficient in terms of sound transmission. Beside thermal insulation of the single layered lightweight concrete walls' regulations, it was found with this study that, it is also necessary to analyze sound transmission lossess, after which the wall cross sections should be sized.

Key Words: *Artificial neuron network (ANN), Lightweight concrete wall, Sound transmit loss*

Hafif Beton Duvarlarda Ses İletim Kaybının Belirlenmesi ve Yapay Sinir Ağının Modellenmesi

ÖZ: Bu makalede, ana yolu trafik gürültüsüne karşı hafif beton duvarlardan ses iletim kayıplarının analizi yapılmıştır. Duvarlar genellikle Türkiye'de ısı yalıtım amacıyla kullanılmaktadır. Ses iletimi ANN kullanılarak modellenmiştir. Giriş parametreleri frekans, hafif beton duvarın yoğunluğu ve hafif beton duvar yapısının kalınlığı (f, M, d2) ve çıkış parametresi TS tanımlanmıştır. TS analizinin sonuçları ve modelleme sonuçları birlikte özetlendiğinde; ses iletimi kayıpları daha yüksek frekanslar, daha yüksek duvar yoğunlukları ve artan duvar kesitleri ile gelişir. Türkiye standart Enstitüsü (TSE 825) tarafından öngörülen tek katmanlı hafif beton duvarların yeterli ısı yalıtımına bakılmaksızın, duvar kesitlerinin ses iletimi açısından yetersiz olduğu bulunmuştur. Tek katmanlı hafif beton duvarların düzenlemelerinin ısı yalıtımının yanı sıra, bu çalışmada, ses iletimi kayıplarını analiz etmek için de gerekli olduğu ve daha sonra duvar kesitlerinin boyutlandırılması gerektiği bulunmuştur.

Anahtar Kelimeler: *Yapay sinir ağı, Hafif beton duvar, Ses iletim kaybı*

Nomenclature

d thickness of lightweight concrete wall, m
f frequency, Hz
L_m suggested noise criteria in various indoor areas, dB
L_o main artery noise level, dB
M density of lightweight concrete wall, kg m^{-3}

MRE mean relative error
R overall thermal resistance value, $m^2 KW^{-1}$
R_i inner surfaces, $m^2 KW^{-1}$
R_o outer surfaces, $m^2 KW^{-1}$
R_0 sound reduction index, dB
R_w total thermal resistance of the lightweight concrete wall
STL sound transmission loss, dB
TS transmitted sound, dB
U thermal conductivity, $W m^{-1} K^{-1}$
L difference between sound transmission loss of lightweight concrete walland suggested noise criteria in various indoor occupied functional areas, dB
$L_{1/1, max value}$ maximum value for 1st climatic region/1st indoor areas, dB
$L_{1/1, min value}$ minimum value for 1st climatic region/1st indoor areas, dB
$L_{1/1, crv}$ criteria value for 1st climatic region/1st indoor areas, dB

INTRODUCTION

There are various methods for predicting sound transmission loss of walls and floors that can be used by noise control engineers. It is important to know how accurate these methods are for typical constructions used in building acoustics. Results are presented for a number of different constructions showing how accurately the results of predictions match experimental laboratory results. The results will show the accuracy over the frequency range of 50 to 5,000 Hz. Both single and double partitions will be discussed. (Ballagh, 2004). There have been many studies on sound transmission loss in walls. Some are briefly mentioned below. Vigran (2009) conducted a study on prediction of sound reduction index of finite size specimen by a simplified spatial windowing technique. Legault and Atalla presented numerical and experimental investigation of the effect of structural links on the sound transmission of a lightweight double panel structure. Wang et al., (2005) examined sound transmission through lightweight double-leaf partitions by using a theoretical modelling. They noted that theoretical modelling of the sound transmission loss through double-leaf lightweight partitions stiffened with periodically placed studs. The models are used to explain the effects of incidence angle and of various system parameters. The predictions are compared with the existing test data for steel plates with wooden stiffeners, and good agreement is obtained.

Double drywalls composed of plasterboards have excellent characteristics such as light weight, easy installation, fire resistance and high sound insulation performance, and are often used for separating walls in apartment houses, hotels and office buildings. Recently, the requirement for sound insulation of building walls has become more strict according to the change in lifestyle and the standard of living. In addition, drywall construction is often applied to recording studios and cinema-complex buildings. In such cases, an extremely high sound insulation performance is required (Matsumoto et al., 2006). Active noise control technology has been used to increase the sound transmission loss of double-wall structures. Several approaches have been put forward and explored individually. However, no comparative study on those approaches has been conducted to show which approach is more effective for given circumstances (Bao and Pan, 1997). There are a variety of noise sources within the indoor noise environment of residential buildings. In particular, multi-storey buildings or neighboring apartment units which share wall, ceiling and floor structures provide structure-borne sound paths for the propagation of floor impact, airborne, and drainage noises (Jeona et al., 2010). The action of courtyard houses in reducing the noise nuisance from road traffic is examined using the techniques of computer simulation and acoustic scale modelling. This building form is found to be capable of reducing the noise level experienced within a protected space (indoor or outdoor) by a significant amount. For a courtyard house a fixed distance from a roadway, the most significant parameter, is found to be the height of the courtyard walls (Oldhama and Mohsen, 2003) .

ANNs are good for some tasks while lacking in some others. Specifically, they are good for tasks involving incomplete data sets, fuzzy or incomplete information, and for highly complex and ill-defined problems, where humans usually decide on an intuitional basis. They can learn from examples, and are able to deal with non-linear problems. Furthermore, they exhibit robustness and fault tolerance. The tasks that ANNs cannot handle effectively are those requiring high accuracy and precision as in logic and arithmetic. ANNs have been applied successfully in a number of application areas (Kalogirou, 2003). An artificial neural network is a model of a biological neural network. The fundamental processing element of a neural network is a neuron, while the weighted connection is served as the synapse. The neuron receives inputs through the weighted connections, combines them in some way, performs generally a nonlinear operation on the result and then outputs the final result. ANNs have large numbers of neurons connected in a massive paralel structure (Zhang, 2005). ANN methods are applied in thermal energy practices, and also in different sub-disciplines of engineering science such as modeling of a thermal insulation system based on the coldest temperature conditions, (Tosun and Dincer, 2011), modeling fuel consumption in wheat production (Safa and Samarasinghe, 2013), analysis of total energy efficiency and optimization in an industrial sector (Olanrewaju et al., 2012), modeling of heating and cooling performance of counter flow type vortex tube by (Kocabas et al., 2010), and in air cooled heat exchangers (Kumar et al., 2006).

In this study, analysis of sound transmission loss through the lightweight concrete walls was made against highway trafic noises and then modeled with ANN. These walls are generally used for thermal insulation in Turkey. The results of the analysis conducted on 11 different background noises in various indoor occupied functional activity areas show that, on 4 different climatic regions in Turkey, the sound transmit loss on climatic regions with small cross sections is insufficient and that the sound transmit loss improves with the increasing cross section area of the walls. However; on the 4th climatic region, it was found that there is no need of insulation material in this region and that the sound insulation was sufficient. In addition; it was found that as the density of the lightweight concrete wall increases, the sound transmit loss improves too. In terms of frequency, it was found that the higher the frequency the better the sound insulation would become. This study found out that some walls with sufficient thermal insulation still need sound insulation especially inner areas that need extra quiteness. Sound transmission against highway traffic noise on 11 different inner activity areas of outer walls made of lightweight concrete was modelled with the ANN . 75 dB trafic noise level, frequency range of 100-4000 Hz and lightweight concrete walls having a density range of 400-800 kg m^{-3} were taken as the basis of the modeling. 2, 3, 4, and 5 neurons were used on the ANN model and the best result was achieved at the 1000 epoch on neuron 2. The actual values and ANN results were found to be consistent to each other (training data R^2 =99.49 and for the testing data R^2 = 99.51)

THEORY

The most basic definition of foamed concrete (cellular concrete, lightweight conrete) is that it is "mortar with air bubbles in it." The air content of foamed concrete may be up to 75% by volume. In general terms, foamed concrete can be described as a lightweight, free flowing material which is ideal for a wide range of applications. Foam concrete has excellent applications, not only as an insulation material, but also for other structural uses like wall blocks, floor or roof panels, sun-breakers, chajjas etc. In addition, it has sound deadening properties. Being essentially a structure composed of closed cells, it has low moisture absorption capacity. The type of lightweight concrete wall used in this study is given in Fig. 1.

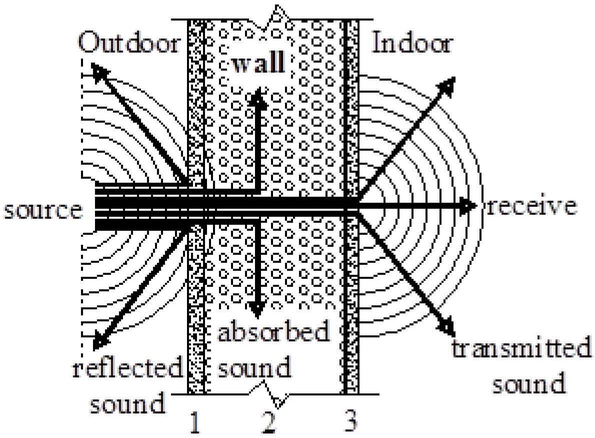

Figure 1. Lightweight concrete wall

The thermal insulation of the lightweight concrete wall, represented by the overall thermal transmittance values U, has to be measured to calculate the heat losses towards the ambiance. In order to be able to measure the heat losses of a building, the U value (the overall thermal transmittance values) of lightweight concrete walls of the building must be calculated. U is defined as follows:

$$U = [R_i + R_w + R_o]^{-1} \tag{1}$$

where U is the overall heat transfer coefficient, R_i and R_o, are inner and outer surfaces' thermal resistance values, 0.13 $m^2\ kW^{-1}$ and 0.04 $m^2\ kW^{-1}$ respectively. The U values used in this study are presented in Table 1. R_w is the total thermal resistance of the lightweight concrete wall materials (TS 825, 2008). R_w is calculated by using Eq. 2

$$R_w = \left[\frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3}\right] \tag{2}$$

Table 1. U and d data for climatic regions of Turkey

Climatic region	U, $Wm^{-2}k^{-1}$	d_2, cm
1	0.70	19
2	0.60	22
3	0.50	26
4	0.40	32

where d is the materials thickness and λ is thermal conductivity of the material.
Lightweight concrete wall thicknesses (d_2) for the 4 climatic regions of Turkey are given in Table 1 whereas the classification of walls based on their respective densities (400-800 kg m^{-3}) is shown in Table 2.

Table 2. Light concrete classes (suitable to TS EN 771- 4 and walls made of blocks with normal pattern thickness and concrete mix)

Foam concrete structural plates	Density, M= kg m^{-3}
1	400
2	500
3	600
4	700
5	800

The sound transmission loss (STL) between the source and receiving rooms are plotted on a graph by frequency and sound level in decibels. STL (R_0) can be calculated from Eq. 3

$$R_0 = 20\log(f.M) - 45 \quad (3)$$

where R_0 is the sound reduction index. Here M is the surface density of board material and f is the frequency (Özer, 1979). The difference (L) between noise criteria range for steady background (Table 3) and the sound transmitted from the lightweight concrete wall to the indoor areas can be calculated with the below equation:

$$\Delta L = L_m - (L_o - R_0) \quad (4)$$

where L_m is the suggested noise criteria in various indoor occupied functional areas, L_o is the main artery noise level, R_o is the sound reduction index, TS is the transmitted sound. If Eq. 4 is rearranged according to TS, then equation 5 can be written as below:

$$\Delta L = L_m - TS \quad (5)$$

DEVELOPED ANN FOR THE SOUND TRANSMISSION OF LIGHTWEIGHT CONCRETE WALLS AGAINST HIGHWAY NOISES

ANNs mimic somewhat the learning process of a human brain. Instead of complex rules and mathematical routines, ANNs are able to learn the key information patterns within a multidimensional information domain. In addition, the inherently noisy data do not seem to present a problem, since they are neglected (Kalogirou and Bojic, 2000) . Artificial neural network is a type of artificial intelligence technique that mimics the behavior of human brain. It can approximate a nonlinear relationship between the input variables and the output of a complicated system (Yang et al., 2005).

In this study, light concrete walls' sound transmissions were modelled with ANN for 11 different buildings subjected to highway noises at the level of 75 decibals. Due to the fact that dimensioning of outer shell of all thermal insulated buildings in Turkey is to be based on the TSE 825 standard, the modeling of the ANN used for this study has been based on this same standard too. As ANN input parameters d_2, f, M were used, while the TS was the output parameter. Where d_2 represents wall thickness; M is wall density and f, frequency. During modeling, these values were assigned: d_2= 19, 22, 26, 32 cm, M= 400, 500, 600, 700, 800 kg m^{-3}, and f= 100, 200, 500, 1000, 2000, 4000 Hz. The thickness of wall (d_2) is calculated from Eq. 2. 120 data sets were obtained from the data list and 60 (1st and 3rd climatic regions) of them were chosen for training, whereas 30 (2nd climatic region) of them were chosen for testing. 30 data sets (4th climatic region) were estimated with the ANN modeling. All the data were chosen randomly and normalized within the range of 0-1 for the ANN modeling by using the operator given in Eq. 6.

Table 3. Recommended category classification and suggested noise criteria range for steady background noise as heard in various indoor occupied functional activity areas

Type of space (and acoustical requirements)	NC Curve	Approximate L_m, dB
1. Broadcast and recording studios (distant microphone pickup used),	10	18
concert halls, opera houses, and recital halls (for listening to faint musical sounds)	10-15	18-23
2. Large auditoriums, large drama theaters, and large churches (for very good listening conditions)	Not to exceed 20	28
3. Broadcast, television, and recording studios (close microphone pickup used only)	Not to exceed 25	33
4. Small auditoriums, small theaters, small churches, conference rooms (for very good listening), or executive offices and conference rooms for 50 people (no amplification)	Not to exceed 30	38
5. Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels, etc. (for sleeping, resting, relaxing)	25-40	38-48
6. Private or semiprivate offices, small conference rooms, classrooms, libraries, etc. (for good listening conditions)	30-40	38-48
Living rooms and drawing rooms in dwellings (for conversing or listening to radio and television)	30-40	38-48
7. Large offices, reception areas, retail shops and stores, cafeterias, restaurants, etc. (for moderately good listening conditions)	35-45	43-53
8. Lobbies, laboratory work spaces, drafting and engineering rooms, general secretarial areas (for fair listening conditions)	40-50	48-58
9. Light maintenance shops, industrial plant control rooms, office and computer equipment rooms, kitchens and laundries (for moderately fair listening conditions)	45-55	53-63
10. Shops, garages, etc. (for just acceptable speech and telephone communication). Levels above NC or NCB 60 are not recommended for any office or communication situation	50-60	58-68
11. For work spaces where speech or telephone communication is not required, but where there must be *no risk* of hearing damage	55-70	63-78

$$Z = \frac{Z_{N-}Z_{\min}}{Z_{\max -}Z_{\min}} \tag{6}$$

where Z_N is the normalized value of a variable, Z is a real value in a paremeter, Z_{max} and Z_{min} are the maximum and minimum values of Z, respectively. In Fig. 2 ANN architecture used for d_2 is schematically shown. The ANN model developed on Matlab software was tested at the values of 100, 250, 500, 1000 epochs for 2, 3, 4 and 5 neurons respectively. The best result was found at neuron 2.

RESULTS AND DISCUSSION

Excessive noise seriously harms human health and interferes with people's daily activities at school, at work, at home and during leisure time. It can disturb sleep, cause cardiovascular and psychophysiological effects, reduce performance and provoke annoyance responses and changes in social behaviour. Traffic noise alone is harming the health of almost every third person in the WHO European Region. The 2009 WHO night noise guidelines for Europe provide both evidence and recommendations that countries can easily use to introduce targeted limits for night noise. WHO/Europe uses the evidence on the health effects of noise to identify the needs of vulnerable groups and to offer technical and policy guidance to protect health (WHO, 2012).

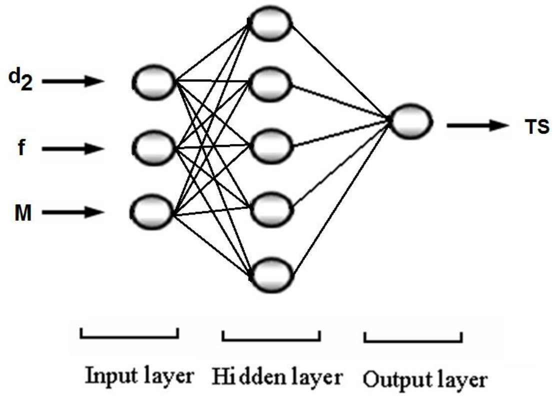

Figure 2. ANN architecture used for d_2

Noise ranges that are considered to cause no health damages at different occusions are presented in Table 3. (Beranek and Ver, 1992) Sound insulation is necessary in areas that receive unacceptably high levels of highway noises and the values for the noise climate found in situations where traffic noise predominates are presented in Table 4 (Croome, 1992).

Table 4. Noise climate found in situations where traffic noise predominates

Group	Location	Noise climate, dB	
		Day	Night
A	Arterial roads with many heavy vehicles and buses (kerbside)	80-68	68-50
B	(i) Major roads with heavy traffic and buses (ii) Side roads within 14-18 m of A or B group road	75-63	61-48
C	(i) Residential roads (ii) Side roads within 14-18 m of heavy traffic routes (iii) Courtyards of blocks of flats screened from direct view of heavy traffic	70-60	54-44
D	Residential roads with local traffic only	65-57	52-44
E	(i) Minor roads (ii) Gardens of houses with traffic routes more than 61 m distant	60-52	48-43
F	Parks, courtyards, gardens in residential areas well away from traffic routes	55-50	46-41

ANNs have been used widely in many application areas. Researchers have been applying the ANN technique successfully in various fields of mathematics, engineering, medicine, economics and many other areas. ANNs have been trained to overcome the limitations of the conventional approaches to solve complex problems. This technique learns from given examples by constructing an input–output mapping in order to perform predictions (Kalogirou, 2000). In this study, analysis was conducted on sound transmission loss of single layered lightweight concrete walls used widely in Turkey and that provide sufficient thermal insulation (based on TSE standards (Tables 5-8), then the transimitted sound was modeled with ANN (Figs.3-6). The analysis of the lightweight concrete walls based on their noise level threshold and the results of the ANN model were investigated in 4 situations.

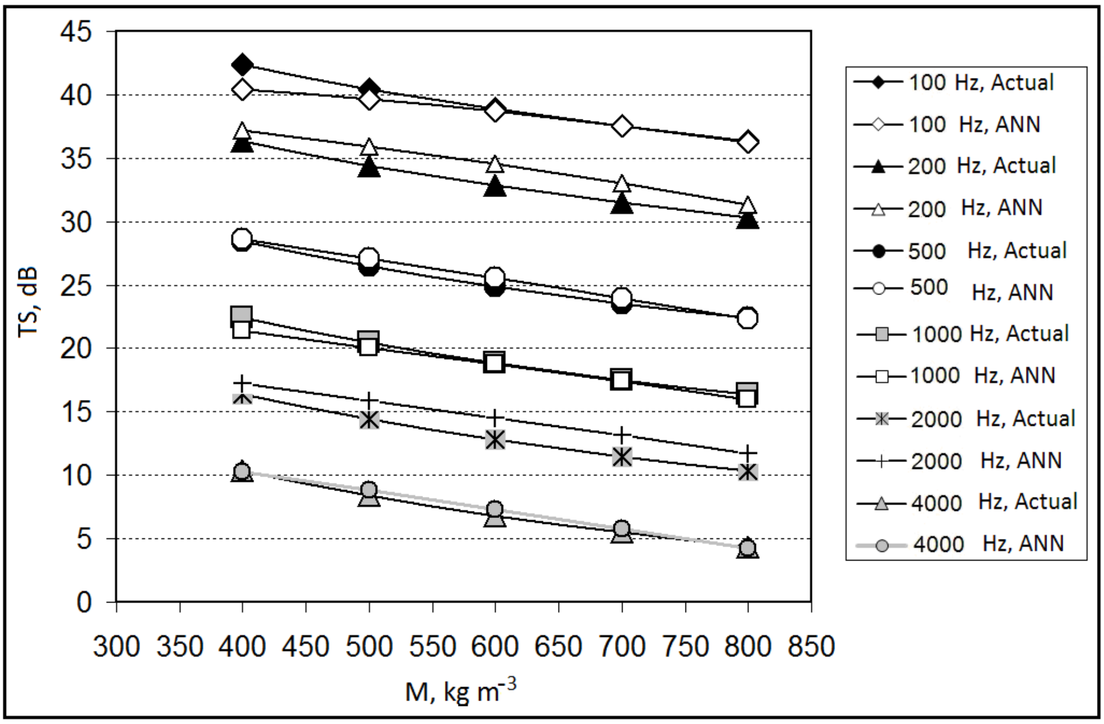

Figure 3. Comparison of actual data with ANN for TS, based on frequency (training-1st climatic region)

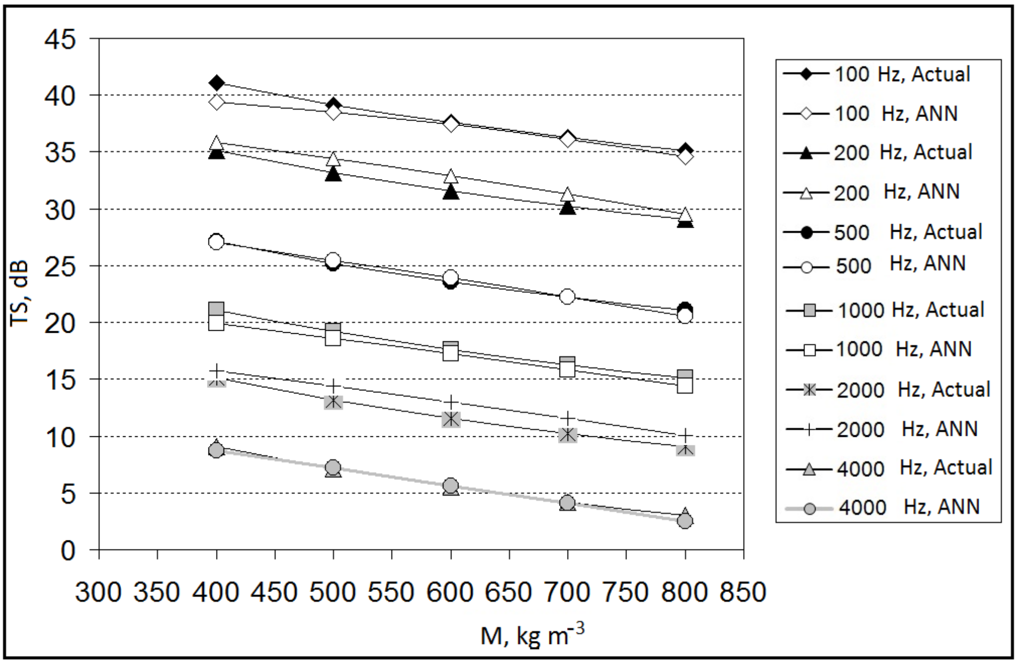

Figure 4. Comparison of actual data with ANN for TS, based on frequencies (test-2nd climatic region)

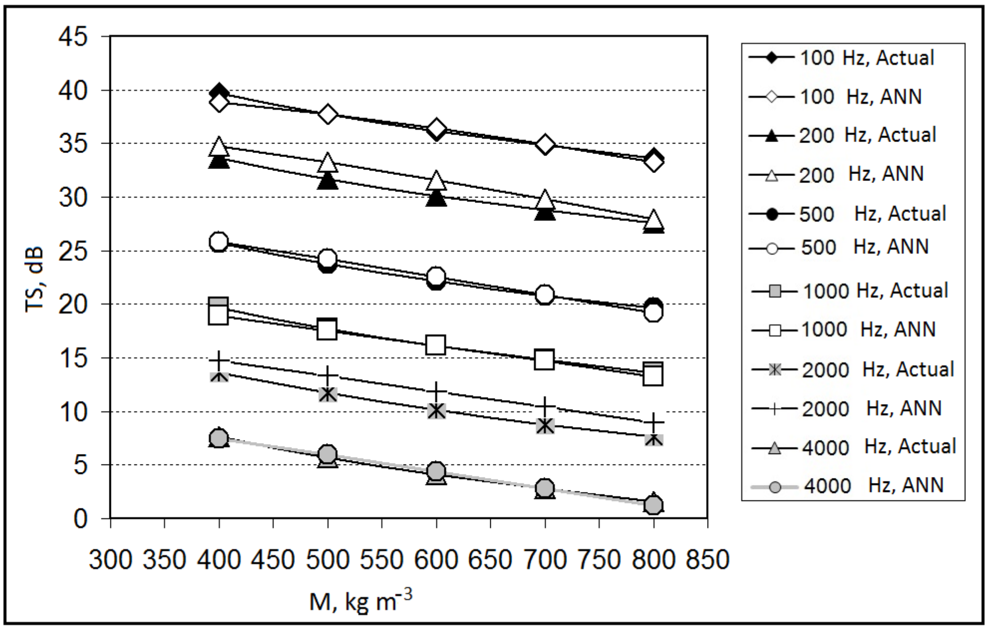

Figure 5. Comparison of actual data with ANN for transmitted sound, based on frequency (training-3rd climatic region)

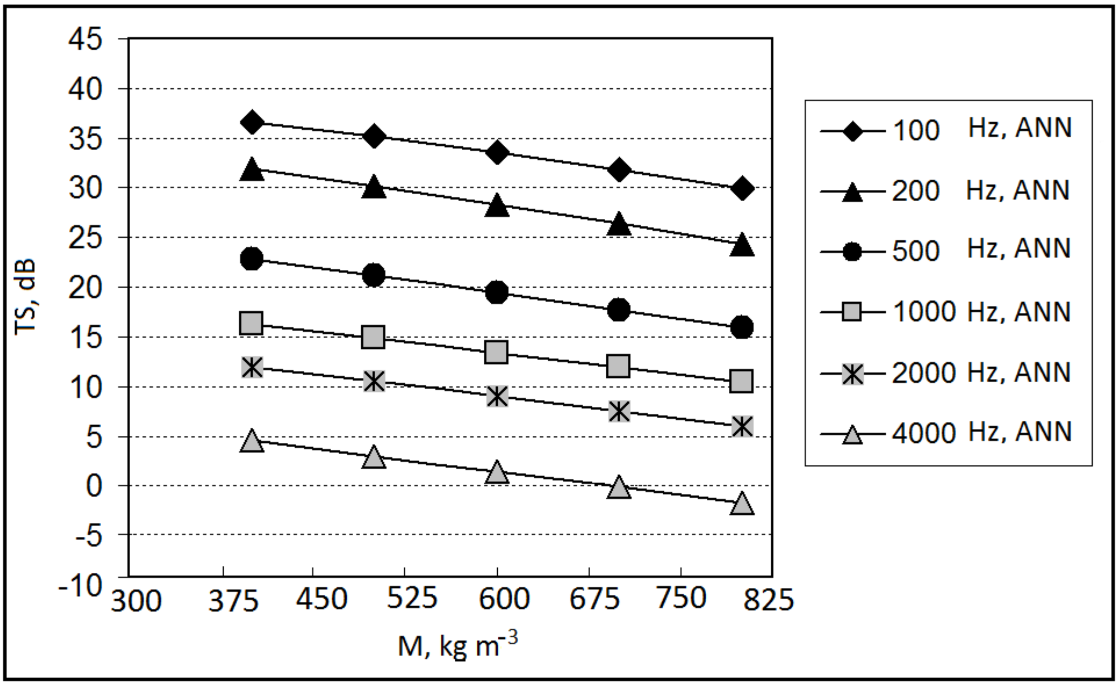

Figure 6. Variations of TS with respect to frequency (ANN-prediction-4th climatic region)

Situation for the 1st Climatic Region of Wall Thickness - L_m for STL

According to TSE 825 standard, the lightweight concrete wall thickness sufficient for thermal insulation in the 1st climatic region is d_2=19 cm (Table 1). The values of wall thickness d_2, density M and frequency f, for transmitted sound (TS) analysis (↞*L*) in the 1st climatic region are presented in Table 5. The worst case for the 1st climatic region is observed between sections 1 and 5 as given in Table 3. The values for the 1st spaces are as given below; $\Delta L_{1/1,\ min\ value}$= **-**24.38 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{1/1,crv}$ =0.48 dB, f=1000 Hz, M=700 kg m^{-3}; $\Delta L_{1/1,\ max\ value}$ = 13.68 dB, f=4000 Hz, M=800 kg m^{-3}; As for sections in the 2nd spaces, the values are; $\Delta L_{1/2,\ min\ value}$= -19.38 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{1/2,crv}$ = 0.62 dB, f=500 Hz, M=800 kg m^{-3}; $\Delta L_{1/2,\ max\ value}$ = 18.68 dB, f=4000 Hz, M=800 kg m^{-3}; in the 3rd spaces were found to bear these values; $\Delta L_{1/3,\ min\ value}$= -14.38 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{1/3,crv}$ =1.53 dB, f=500 Hz, M=500 kg m^{-3}; $\Delta L_{1/3,\ max\ value}$ = 23.68 dB, f=4000 Hz, M=800 kg m^{-3}; the study also found that the 4th spaces exhibit these entities; $\Delta L_{1/4,\ min\ value}$= -9.38 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{1/4,crv}$ = 0.16 dB, f=200 Hz, M=600 kg m^{-3}; $\Delta L_{1/4,\ max\ value}$ = 28.68 dB, f=4000 Hz, M=800 kg m^{-3}; spaces in the 5th were found to have these values; $\Delta L_{1/5,\ min\ value}$= -4.38 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{1/5,crv}$ = 0.48 dB, f=100 Hz, M=700 kg m^{-3}; $\Delta L_{1/5,\ max\ value}$ = 33.68 dB, f=4000 Hz, M=800 kg m^{-3}. No negative cases for the 1st climatic region were found between 6 -11 spaces as listed in Table 3 where there is steady background noise as heard in various indoor occupied functional activity areas. The best cases for spaces 6-11 were observed at f=4000 Hz ve M=800 kg m^{-3}. These are; $\Delta L_{1/6,\ max\ value}$ = 43.68 dB, $\Delta L_{1/7,\ max\ value}$ = 48.68 dB, $\Delta L_{1/8,\ max\ value}$ = 53.68 dB, $\Delta L_{1/9,\ max\ value}$ = 58.68 dB, $\Delta L_{1/10,\ max\ value}$ = 63.68 dB, $\Delta L_{1/11,\ max\ value}$ = 73.68 dB. Fig.3 shows variation of ANN data and actual data with respect to frequency and TS for the 1st climatic region.

Table 5. ΔL for lightweight concrete wall in 1st climatic region

	Steady background noise as heard in various indoor occupied functional activity areas										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
d=19 for f, M	**-**	**-**	**-**	**-9.38**	**-4.38**	5.62	10.62	15.62	20.62	25.62	35.62
	-	**-**	**-**	**-7.45**	**-2.45**	7.55	12.55	17.55	22.55	27.55	37.55
	-	**-**	**-**	**-5.86**	**- 0.86**	9.14	14.14	19.14	24.14	29.14	39.14
	-	**-**	**-9.52**	**-4.52**	0.48	10.48	15.48	20.48	25.48	30.48	40.48
	-	**-**	**-8.36**	**-3.36**	1.64	11.64	16.64	21.64	26.64	31.64	41.64
	-	**-**	**-8.36**	**-3.36**	1.64	11.64	16.64	21.64	26.64	31.64	41.64
	-	**-**	**-6.42**	**-1.42**	3.58	13.58	18.58	23.58	28.58	33.58	43.58
	-	**- 9.84**	**-4.84**	0.16	5.16	15.16	20.16	25.16	30.16	35.16	45.16
	-	**- 8.50**	**-3.50**	1.50	6.50	16.50	21.50	26.50	31.50	36.50	46.50
	-	**- 7.34**	**-2.34**	2.66	7.66	17.66	22.66	27.66	32.66	37.66	47.66
	-	**- 5.40**	**-0.40**	4.60	9.60	19.60	24.60	29.60	34.60	39.60	49.60
	- 8.47	**- 3.47**	1.53	6.53	11.53	21.53	26.53	31.53	36.53	41.53	51.53
	- 6.88	**- 1.88**	3.12	8.12	13.12	23.12	28.12	33.12	38.12	43.12	53.12
	- 5.54	**- 0.54**	4.46	9.46	14.46	24.46	29.46	34.46	39.46	44.46	54.46
	- 4.38	0.62	5.62	10.62	15.62	25.62	30.62	35.62	40.62	45.62	55.62
	- 4.38	0.62	5.62	10.62	15.62	25.62	30.62	35.62	40.62	45.62	55.62
	- 2.45	2.55	7.55	12.55	17.55	27.55	32.55	37.55	42.55	47.55	57.55
	- 0.86	4.14	9.14	14.14	19.14	29.14	34.14	39.14	44.14	49.14	59.14
	0.48	5.48	10.48	15.48	20.48	30.48	35.48	40.48	45.48	50.48	60.48
	1.64	6.64	11.64	16.64	21.64	31.64	36.64	41.64	46.64	51.64	61.64
	1.64	6.64	11.64	16.64	21.64	31.64	36.64	41.64	46.64	51.64	61.64
	3.58	8.58	13.58	18.58	23.58	33.58	38.58	43.58	48.58	53.58	63.58
	5.16	10.16	15.16	20.16	25.16	35.16	40.16	45.16	50.16	55.16	65.16
	6.50	11.50	16.50	21.50	26.50	36.50	41.50	46.50	51.50	56.50	66.50
	7.66	12.66	17.66	22.66	27.66	37.66	42.66	47.66	52.66	57.66	67.66
	7.66	12.66	17.66	22.66	27.66	37.66	42.66	47.66	52.66	57.66	67.66
	9.60	14.60	19.60	24.60	29.60	39.60	44.60	49.60	54.60	59.60	69.60
	11.18	16.18	21.18	26.18	31.18	41.18	46.18	51.18	56.18	61.18	71.18
	12.52	17.52	22.52	27.52	32.52	42.52	47.52	52.52	57.52	62.52	72.52
	13.68	18.68	23.68	28.68	33.68	43.68	48.68	53.68	58.68	63.68	73.68

Situation for the 2nd Climatic Region of Wall Thickness - L_m for STL

The 2nd climatic region according to the TSE 825 standard should have lightweight concrete wall thickness of 22 cm (d_2=22 cm-see Table 1) in order to achieve sufficient thermal insulation. The TS analysis (✈L) for the 2nd climatic region in terms of wall thickness d_2 , density M and frequency,f is presented in Table 6.

The worst case for the 2nd climatic region as given in Table 3 occurred on sections 1-5. The values for the 1st spaces were found to be; ✈$L_{2/1,\text{ min value}}$= -23.11 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{2/1,\text{crv}}$ 0.41 dB, f=1000 Hz, M=600 kg m^{-3}; ✈$L_{2/1,\text{ max value}}$ = 14.95, f=4000 Hz, M=800 kg m^{-3}; for the 2nd spaces, the values were; ✈$L_{2/2,\text{ min value}}$= -18.11 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{2/2,\text{crv}}$ = 0.73 dB, f=500 Hz, M=700 kg m^{-3}; ✈$L_{2/2,\text{ max value}}$ =19.95 dB, f=4000 Hz, M=800 kg m^{-3}; the 3rd spaces had these values; ✈$L_{2/3,\text{ min value}}$= -13.11 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{2/3,\text{crv}}$ = 0.87 dB, f=500 Hz, M=400 kg m^{-3}; ✈$L_{2/3,\text{ max value}}$ = 24.95 dB, f=4000 Hz, M=800 kg m^{-3}; values for the 4th spaces were; ✈$L_{2/4,\text{ min value}}$= -8.11 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{2/4,\text{crv}}$ = 1.43 dB, f=200 Hz, M=600 kg m^{-3}; ✈$L_{2/4,\text{ max value}}$ = 29.95 dB, f=4000 Hz, M=800 kg m^{-3}; the 5th space's values were ; ✈$L_{2/5,\text{ min value}}$= -3.11 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{2/5,\text{crv}}$ = 0.41 dB, f=100 Hz, M=600 kg m^{-3}; ✈$L_{2/5,\text{ max value}}$ = 34.95 dB, f=4000 Hz, M=800 kg m^{-3}. In terms of sound transmission for the 2nd climatic region, (Table 3) no negative observation was recorded for spaces 6-11. The best case on these spaces (6-11) exhibited these conditions, f=4000 Hz ve M=800 kg m^{-3}, Where the values were; ✈$L_{2/6,\text{ max value}}$ = 44.95 dB, ✈$L_{2/7,\text{ max value}}$ = 49.95 dB, ✈$L_{2/8,\text{ max value}}$ = 54.95 dB, ✈$L_{2/9,\text{ max value}}$ = 59.95 dB, ✈$L_{2/10,\text{ max value}}$ = 64.95 dB, ✈$L_{2/11,\text{ max value}}$ = 74.95 dB. In Fig. 4, variation of actual and ANN data with respect to frequency and TS for the 2nd climatic region is presented.

Situation for 3rd Climatic Region of Wall Thickness - L_m for STL

According to the TSE 825 standard, the thickness of lightweight concrete wall sufficient for thermal insulation for the 3rd climatic region is d_2=26 cm (Table 1). The values of d_2, M and f for TS analysis (✈L) for the 3rd climatic region is presented in Table 7.
f=200 Hz, M=800 kg/m^3; ✈$L_{3/3,\text{ max value}}$ = 26.40 dB, f=4000 Hz, M=800 kg m^{-3}; as for the 4th spaces, the values were; ✈$L_{3/4,\text{ min value}}$= -6.66 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{3/4,\text{crv}}$ = 1.30 dB, f=200 Hz, M=500 kg m^{-3}; ✈$L_{3/4,\text{ max value}}$ = 31.40 dB, f=4000 Hz, M=800 kg m^{-3}; values for the 5th spaces were found to be; ✈$L_{3/5,\text{ min value}}$= -1.66 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{3/5,\text{crv}}$ = 0.28 dB, f=100 Hz, M=500 kg m^{-3}; ✈$L_{3/5,\text{ max value}}$ = 36.40 dB, f=4000 Hz, M=800 kg m^{-3}. As for the 3rd climatic region, among the sections 6-11 in Table 3, no negative aspects in terms of sound level were found for sections 6th - 11th whereas the best case for 6-11 spaces in the 3rd climatic region took space under these conditions of frequency and density, f=4000 Hz and M=800 kg m^{-3} respectively. Here, it is found that; ✈$L_{3/6,\text{ max value}}$ = 46.40 dB, ✈$L_{3/7,\text{ max value}}$ = 51.40 dB, ✈$L_{3/8,\text{ max value}}$ = 56.40 dB, ✈$L_{3/9,\text{ max value}}$ = 61.40 dB, ✈$L_{3/10,\text{ max value}}$ = 66.40 dB, ✈$L_{3/11,\text{ max value}}$ = 76.40 dB. Fig. 5 shows variation of ANN and actual data for the 3rd climatic region based on frequency and TS.

The most negative case for the 3rd climatic region appears on sections 1-5 as shown on Table 3. For the 1st spaces, the following values were found; ✈$L_{3/1,\text{ min value}}$= -21.66 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{3/1,\text{crv}}$ = 0.28 dB, f=1000 Hz, M=500 kg m^{-3}; ✈$L_{3/1,\text{ max value}}$ = 16.40 dB, f=4000 Hz, M=800 kg m^{-3}; For the 2nd spaces, the values found were ✈$L_{3/2,\text{ min value}}$= -16.66 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{3/2,\text{crv}}$ = 0.84 dB, f=500 Hz, M=600 kg m^{-3}; ✈$L_{3/2,\text{ max value}}$ = 21.40 dB, f=4000 Hz, M=800 kg m^{-3}; the 3rd spaces had; ✈$L_{3/3,\text{ min value}}$= -11.66 dB, f=100 Hz, M=400 kg m^{-3}; ✈$L_{3/3,\text{crv}}$ = 0.38 dB,

Table 6. ΔL for lightweight concrete wall in 2nd climatic region

	Steady background noise as heard in various indoor occupied functional										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
d=22 for f, M	**-**	**-**	**-**	**-8.11**	**-3.11**	6.89	11.89	16.89	21.89	26.89	36.89
	-	**-**	**-**	**-6.17**	**-1.17**	8.83	13.83	18.83	23.83	28.83	38.83
	-	**-**	**-9.59**	**-4.59**	0.41	10.41	15.41	20.41	25.41	30.41	40.41
	-	**-**	**-8.25**	**-3.25**	1.75	11.75	16.75	21.75	26.75	31.75	41.75
	-	**-**	**-7.09**	**-2.09**	2.91	12.91	17.91	22.91	27.91	32.91	42.91
	-	**-**	**-7.09**	**-2.09**	2.91	12.91	17.91	22.91	27.91	32.91	42.91
	-	**-**	**-5.15**	**-0.15**	4.85	14.85	19.85	24.85	29.85	34.85	44.85
	-	**-8.57**	**-3.57**	1.43	6.43	16.43	21.43	26.43	31.43	36.43	46.43
	-	**-7.23**	**-2.23**	2.77	7.77	17.77	22.77	27.77	32.77	37.77	47.77
	-	**-6.07**	**-1.07**	3.93	8.93	18.93	23.93	28.93	33.93	38.93	48.93
	-9.13	**-4.13**	0.87	5.87	10.87	20.87	25.87	30.87	35.87	40.87	50.87
	-7.19	**-2.19**	2.81	7.81	12.81	22.81	27.81	32.81	37.81	42.81	52.81
	-5.61	**-0.61**	4.39	9.39	14.39	24.39	29.39	34.39	39.39	44.39	54.39
	-4.27	0.73	5.73	10.73	15.73	25.73	30.73	35.73	40.73	45.73	55.73
	-3.11	1.89	6.89	11.89	16.89	26.89	31.89	36.89	41.89	46.89	56.89
	-3.11	1.89	6.89	11.89	16.89	26.89	31.89	36.89	41.89	46.89	56.89
	-1.17	3.83	8.83	13.83	18.83	28.83	33.83	38.83	43.83	48.83	58.83
	0.41	5.41	10.41	15.41	20.41	30.41	35.41	40.41	45.41	50.41	60.41
	1.75	6.75	11.75	16.75	21.75	31.75	36.75	41.75	46.75	51.75	61.75
	2.91	7.91	12.91	17.91	22.91	32.91	37.91	42.91	47.91	52.91	62.91
	2.91	7.91	12.91	17.91	22.91	32.91	37.91	42.91	47.91	52.91	62.91
	4.85	9.85	14.85	19.85	24.85	34.85	39.85	44.85	49.85	54.85	64.85
	6.43	11.43	16.43	21.43	26.43	36.43	41.43	46.43	51.43	56.43	66.43
	7.77	12.77	17.77	22.77	27.77	37.77	42.77	47.77	52.77	57.77	67.77
	8.93	13.93	18.93	23.93	28.93	38.93	43.93	48.93	53.93	58.93	68.93
	8.93	13.93	18.93	23.93	28.93	38.93	43.93	48.93	53.93	58.93	68.93
	10.87	15.87	20.87	25.87	30.87	40.87	45.87	50.87	55.87	60.87	70.87
	12.45	17.45	22.45	27.45	32.45	42.45	47.45	52.45	57.45	62.45	72.45
	13.79	18.79	23.79	28.79	33.79	43.79	48.79	53.79	58.79	63.79	73.79
	14.95	19.95	24.95	29.95	34.95	44.95	49.95	54.95	59.95	64.95	74.95

Table 7. ΔL for lightweight concrete wall in 3rd climatic region

	Steady background noise as heard in various ındoor occupied functional activity areas										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
d=26 for f, M	**-21.66**	**-16.66**	**-11.66**	**-6.66**	**-1.66**	8.34	13.34	18.34	23.34	28.34	38.34
	-19.72	**-14.72**	**-9.72**	**-4.72**	0.28	10.28	15.28	20.28	25.28	30.28	40.28
	-18.14	**-13.14**	**-8.14**	**-3.14**	1.86	11.86	16.86	21.86	26.86	31.86	41.86
	-16.80	**-11.80**	**-6.80**	**-1.80**	3.20	13.20	18.20	23.20	28.20	33.20	43.20
	-15.64	**-10.64**	**-5.64**	**-0.64**	4.36	14.36	19.36	24.36	29.36	34.36	44.36
	-15.64	**-10.64**	**-5.64**	**- 0.64**	4.36	14.36	19.36	24.36	29.36	34.36	44.36
	-13.70	**-8.70**	**-3.70**	1.30	6.30	16.30	21.30	26.30	31.30	36.30	46.30
	-12.12	**-7.12**	**-2.12**	2.88	7.88	17.88	22.88	27.88	32.88	37.88	47.88
	-10.78	**-5.78**	**-0.78**	4.22	9.22	19.22	24.22	29.22	34.22	39.22	49.22
	- 9.62	**- 4.62**	0.38	5.38	10.38	20.38	25.38	30.38	35.38	40.38	50.38
	-7.68	**-2.68**	2.32	7.32	12.32	22.32	27.32	32.32	37.32	42.32	52.32
	-5.74	**- 0.74**	4.26	9.26	14.26	24.26	29.26	34.26	39.26	44.26	54.26
	- 4.16	0.84	5.84	10.84	15.84	25.84	30.84	35.84	40.84	45.84	55.84
	- 2.82	2.18	7.18	12.18	17.18	27.18	32.18	37.18	42.18	47.18	57.18
	-1.66	3.34	8.34	13.34	18.34	28.34	33.34	38.34	43.34	48.34	58.34
	-1.66	3.34	8.34	13.34	18.34	28.34	33.34	38.34	43.34	48.34	58.34
	0.28	5.28	10.28	15.28	20.28	30.28	35.28	40.28	45.28	50.28	60.28
	1.86	6.86	11.86	16.86	21.86	31.86	36.86	41.86	46.86	51.86	61.86
	3.20	8.20	13.20	18.20	23.20	33.20	38.20	43.20	48.20	53.20	63.20
	4.36	9.36	14.36	19.36	24.36	34.36	39.36	44.36	49.36	54.36	64.36
	4.36	9.36	14.36	19.36	24.36	34.36	39.36	44.36	49.36	54.36	64.36
	6.30	11.30	16.30	21.30	26.30	36.30	41.30	46.30	51.30	56.30	66.30
	7.88	12.88	17.88	22.88	27.88	37.88	42.88	47.88	52.88	57.88	67.88
	9.22	14.22	19.22	24.22	29.22	39.22	44.22	49.22	54.22	59.22	69.22
	10.38	15.38	20.38	25.38	30.38	40.38	45.38	50.38	55.38	60.38	70.38
	10.38	15.38	20.38	25.38	30.38	40.38	45.38	50.38	55.38	60.38	70.38
	12.32	17.32	22.32	27.32	32.32	42.32	47.32	52.32	57.32	62.32	72.32
	13.90	18.90	23.90	28.90	33.90	43.90	48.90	53.90	58.90	63.90	73.90
	15.24	20.24	25.24	30.24	35.24	45.24	50.24	55.24	60.24	65.24	75.24
	16.40	21.40	26.40	31.40	36.40	46.40	51.40	56.40	61.40	66.40	76.40

Situation for the 4th Climatic Region of Wall Thickness - L_m for STL

32 cm is the acceptable thickness of a lightweight concrete wall for thermal insulation for the 4th climatic region in TSE 825 (Table 1). TS analysis (ΔL) of d_2, M and f, for the 4th climatic region is shown on Table 8. The 4th climatic region has had its worst case between sections 1 and 4 (Table 3). Here, the 1st spaces acquired the values of ; $\Delta L_{4/1,\ min\ value}$= -19.86 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{4/1,crv}$ = 0.14 dB, f=500 Hz, M=800 kg m^{-3}; $\Delta L_{4/1,\ max\ value}$ = 18.21 dB, f=4000 Hz, M=800 kg m^{-3}; the 2nd spaces exhibited these values; $\Delta L_{4/2,\ min\ value}$= -14.86 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{4/2,crv}$ = 1.06 dB, f=500 Hz, M=500 kg m^{-3}; $\Delta L_{4/2,\ max\ value}$ = 23.21 dB, f=4000 Hz, M=800 kg m^{-3}; while the 3rd spaces indicated; $\Delta L_{4/3,\ min\ value}$= -9.86 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{4/3,crv}$ =1.03 dB, f=200 Hz, M=700 kg m^{-3}; $\Delta L_{4/3,\ max\ value}$ = 28.21 dB, f=4000 Hz, M=800 kg m^{-3}; as for the 4th spaces, the values were; $\Delta L_{4/4,\ min\ value}$= - 4.86 dB, f=100 Hz, M=400 kg m^{-3}; $\Delta L_{4/4,crv}$ = 0.00 dB, f=100 Hz, M=700 kg m^{-3}; $\Delta L_{4/4,\ max\ value}$ = 33.21 dB, f=4000 Hz, M=800 kg m^{-3}. The investigation found no irregularities in terms of sound levels for the 4th climatic region between 5-11; while the best case in these

sections (5-11) occurred at f=4000 Hz and M=800 kg m^{-3}. Here the values are; $\Delta L_{4/5,\ \text{max value}}$ = 38.21 dB, $\Delta L_{4/6,\ \text{max value}}$ = 48.21 dB, $\Delta L_{4/7,\ \text{max value}}$ = 53.21 dB, $\Delta L_{4/8,\ \text{max value}}$ = 58.21 dB, $\Delta L_{4/9,\ \text{max value}}$ = 63.21 dB, $\Delta L_{4/10,\ \text{max value}}$ = 68.21 dB, $\Delta L_{4/11,\text{max value}}$ = 78.21 dB. Fig. 6 shows variation of ANN and actual data for the 4th climatic region based on frequency and TS.

When the Tables 5-8 are evaluated for 1,2,3,4,5 spaces that need strong insulation in Table 3, it is found that the sound transmission losses are not sufficient. These insufficient values were particularly found at these frequencies: 100, 200, 500, 1000 Hz. As for the sections 6-11, the single layer lightweight concrete wall cross sections as recommended by TSE 825, were found to provide sufficient sound transmission loss. This is so because, these areas need no high level sound sensitvity and are generally public areas. With this study, it was found that it is necessary that apart from dimensioning the lightweight single concrete walls for thermal insulation under working frequencies of 100, 200, 500 and 1000 Hz with low densities, sound sensitive spaces described in 1-5 spaces should also be considered in terms of sound transmission losses. In addition, the buildings in the 1st climatic region which need lower thermal insulation were also found to have lower inner sound insulation; and as the need for the thermal insulation increases in the 2nd, 3rd, and 4th climatic regions, the sound insulation increases too. It is therefore determined that thermal and sound transmissions go hand in hand.

Table 8. ΔL for lightweight concrete wall in 4th climatic region

	Steady background noise as heard in various indoor occupied functional activity areas										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
d=32 for f, M	**-19.86**	**-14.86**	**-9.86**	**-4.86**	0.14	10.14	15.14	20.14	25.14	30.14	40.14
	-17.92	**-12.92**	**-7.92**	**-2.92**	2.08	12.08	17.08	22.08	27.08	32.08	42.08
	-16.33	**-11.33**	**-6.33**	**-1.33**	3.67	13.67	18.67	23.67	28.67	33.67	43.67
	-15.00	**-10.00**	**-5.00**	0.00	5.00	15.00	20.00	25.00	30.00	35.00	45.00
	-13.84	**-8.84**	**-3.84**	1.16	6.16	16.16	21.16	26.16	31.16	36.16	46.16
	-13.84	**-8.84**	**-3.84**	1.16	6.16	16.16	21.16	26.16	31.16	36.16	46.16
	-11.90	**-6.90**	**-1.90**	3.10	8.10	18.10	23.10	28.10	33.10	38.10	48.10
	-10.31	**-5.31**	**-0.31**	4.69	9.69	19.69	24.69	29.69	34.69	39.69	49.69
	-8.97	**-3.97**	1.03	6.03	11.03	21.03	26.03	31.03	36.03	41.03	51.03
	-7.81	**-2.81**	2.19	7.19	12.19	22.19	27.19	32.19	37.19	42.19	52.19
	-5.88	**-0.88**	4.12	9.12	14.12	24.12	29.12	34.12	39.12	44.12	54.12
	-3.94	1.06	6.06	11.06	16.06	26.06	31.06	36.06	41.06	46.06	56.06
	-2.35	2.65	7.65	12.65	17.65	27.65	32.65	37.65	42.65	47.65	57.65
	-1.02	3.98	8.98	13.98	18.98	28.98	33.98	38.98	43.98	48.98	58.98
	0.14	5.14	10.14	15.14	20.14	30.14	35.14	40.14	45.14	50.14	60.14
	0.14	5.14	10.14	15.14	20.14	30.14	35.14	40.14	45.14	50.14	60.14
	2.08	7.08	12.08	17.08	22.08	32.08	37.08	42.08	47.08	52.08	62.08
	3.67	8.67	13.67	18.67	23.67	33.67	38.67	43.67	48.67	53.67	63.67
	5.00	10.00	15.00	20.00	25.00	35.00	40.00	45.00	50.00	55.00	65.00
	6.16	11.16	16.16	21.16	26.16	36.16	41.16	46.16	51.16	56.16	66.16
	6.16	11.16	16.16	21.16	26.16	36.16	41.16	46.16	51.16	56.16	66.16
	8.10	13.10	18.10	23.10	28.10	38.10	43.10	48.10	53.10	58.10	68.10
	9.69	14.69	19.69	24.69	29.69	39.69	44.69	49.69	54.69	59.69	69.69
	11.03	16.03	21.03	26.03	31.03	41.03	46.03	51.03	56.03	61.03	71.03
	12.19	17.19	22.19	27.19	32.19	42.19	47.19	52.19	57.19	62.19	72.19
	12.19	17.19	22.19	27.19	32.19	42.19	47.19	52.19	57.19	62.19	72.19
	14.12	19.12	24.12	29.12	34.12	44.12	49.12	54.12	59.12	64.12	74.12
	15.71	20.71	25.71	30.71	35.71	45.71	50.71	55.71	60.71	65.71	75.71
	17.05	22.05	27.05	32.05	37.05	47.05	52.05	57.05	62.05	67.05	77.05
	18.21	23.21	28.21	33.21	38.21	48.21	53.21	58.21	63.21	68.21	78.21

When the results of ANN modeling for the transmitted sound are evaluated together (Figure 3-6), it is found that the maximum sound transmission occurs on the 1st climatic region, at a frequency of 100 Hz, wall density of 400 kgm^{-3} and sound level of 42.38 dB (training) while the minimum sound transmission takes space on the 4th climatic region and at a frequency of 4000 Hz, density of 800 kgm^{-3} and sound level of -1.76 dB (prediction). Some statistical methods are defined as follows: The error during the learning session is called the root-mean-square (RMS) value and is defined as follows (Sözen and Arcaklioglu, 2007):

$$RMS = \left((1/p) \sum_j \left| t_j - o_j \right|^2 \right)^{1/2} \tag{7}$$

In addition, absolute fraction of variance (R^2) and mean absolute percentage error (MAPE) are defined as follows, respectively (Sözen and Arcaklioglu, 2007):

$$R^2 = 1 - \left(\frac{\sum_j (t_j - o_j)^2}{\sum_j (o_j)^2} \right) \tag{8}$$

where t is target value, o is output value, and p is pattern (Sözen and Arcaklioglu, 2007)

$$MAPE = \frac{o - t}{o} x100 \tag{9}$$

The statistical values such as RMS, R^2, MAPE are given in Table 9. When Table 9 is studied, it is found that the ANN values cope well with the actual values.

Table 9. The statistical error values for TS

RMS	R^2(%)	MAPE(%)	ANN
0.89	99.49	2.56	Training
0.15	99.51	1.11	Test

CONCLUSION

In this study, analysis of sound transmission losses through lightweight concrete walls was conducted against the high way trafic noises. The walls are generally used for thermal insulation purposes in Turkey. Sound transmission was modeled using ANN.
The conclusions drawn in this paper are summarized as follows:

- Sound transmission losses improve with higher frequencies, higher wall densities and increased wall cross sections.
- Regardless of sufficient thermal insulation of single layered lightweight concrete walls as stipulated by the Turkey Institute of Standards (TSE 825), the wall cross sections were found to be insufficient in terms of sound transmission (Figures 5-8).

- Beside thermal insulation of the single layered lightweight concrete walls' regulations, it was found with this study that, it is also necessary to analyze sound transmission lossess, after which the wall cross sections should be sized.
- The ANN was trained and tested by means of toolbox of the MATLAB software on a personal computer.
- Input parameters d_2, f, M and output parameter TS were described.
- In modeling the lightweight concrete walls for sound transmission against the highway noises, the back-propagation algorithm has been implemented to calculate errors and adjust weights of the hidden layer neurons. The sigmoid function was chosen as the transfer function. Number of neurons in the hidden layer and epoch numbers were tested for different values (100, 250, 500 and 1000 epoch). The model was tested on 2, 3, 4 and 5 neurons. A network of 2 neurons was chosen as it yielded the most appropriate results.
- R^2 for training the TS is 99.49 % and R^2 for testing the TS is 99.51 %. The actual values and ANN results show that ANN can be successfully used for analyzing sound transmission through lightweight concrete walls against highway noises.

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