Assessment of sound transmission characteristics of traditional timber-framed dwellings in Ankara, Turkey

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Summary
The impact and airborne sound transmission characteristics of interior wall and floor components in traditional timber-framed dwellings (Ankara, Turkey) were examined by in-situ acoustical measurements and simulation analyses. Presence of voids for the running of pipework or door/window openings existed in the composition of timber framed wall and floor components was found to reduce their sound insulation performances in the range of 12-22dB. Air/sound leakages through the openings should be sealed properly in order to provide the required Rw and Lnw values for dwellings. In case that the dwelling units/spaces are used as exhibition, meeting, office or hotel rooms, some acoustical improvements in existing wall and floor components can be provided by demountable attachments with sound insulation infill and sound breaks.

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1. Introduction

Sound transmission characteristics of traditional timber dwellings in Turkey have become a serious issue due to the increase in complaints of residents about noise problems in those structures. There is, therefore, a necessity to examine sound transmission problems in these dwellings with an emphasis on configuration of their timber frame components. Such a study is needed to reveal the necessary remedial works for the improvement of their sound insulation performances while keeping their original features.
Here, some repaired and non-repaired traditional timber framed dwellings were examined with an emphasis on direct and flanking transmission of airborne and impact sound through their interior wall and floor sections. The joint use of in-situ acoustical measurements and simulation analyses allowed the identification of sound transmission problems in those existing structures and their reasons. The results were discussed for the elimination of these problems with minimum intervention.

2. Material and Method

The study was conducted on three traditional timber framed dwellings, Ankara Bağ Evi, Boyacızade Konağı and Tahtacıörencik Village House, located in Ankara. The brief information on the houses is given in Table I. The wall and floor components under examination are listed in Table II and desciption of each layers forming their configuration are shown in Figure 1. In the composition for wall and floor components, there existed opening units which are of paneled doors or windows or some voids for running of pipework, respectively.
The study was composed of the in-situ measurements, simulation analyses and sound reduction performance calculations particularly used for the assessment of composite walls [1, 2, 3]. In-situ measurements were conducted by an

omnidirectional sound source, a tapping machine and a Class 1 sound level meter. Sound reduction performance of the components was estimated by INSUL analyses while sound transmission through the components due to the flanking effect was determined by BASTIAN analyses. The modules of elasticity (MoE) and the density values of the original mudbrick were assigned to be in the ranges of 0.7GPa-7GPa and 1073kg/m^3-1206kg/m^3, respectively [4,5], and then used as input data for the simulation analyses in order to define the original mudbrick as a material in INSUL software. The structural timber elements used in the simulation of original floor configuration were taken to have the density of 630kg/m^3 belonging to sound old pine [6]. The analyses were done to assess airborne and impact sound insulation performance of existing walls and floors in one-third octave band center frequencies. The data was evaluated in terms of weighted sound reduction index, R_W and R'_W (dB), and weighted impact sound pressure level, L_{nw} and L'_{nw} (dB) [7,8]. The evaluations of in-situ and estimated data were conducted according to the required Rw data above 50 and Lnw data below 65 that were defined as acceptable minimum ranges in the Building Regulations of various European countries [9].

A supportive study was carried by calculations defined in Equation 1 [3], particularly for the assessment of a wall section for its solid part (without an opening) and as a composite wall composed of its solid part and opening) in the case of sound reduction index of door or window is at least 15 dB lower than the sound reduction value of solid part of wall component [3].

$$R_{WC} = R_{W2} + 10\log(1 + S_1/S_2) \quad (1)$$

where R_{WC} is the composite sound reduction index of wall including door/window (dB), R_{W2} is the sound reduction index of door/window (dB), S_1 is the surface area of the wall excluding the area of door/window opening (m^2), S_2 is the surface area of the door/window (m^2).

Table I. Brief definition of traditional timber frame dwellings.

Timber frame structures	Situation	As-Is Function
Ankara Bağ Evi	Reconstructed	Museum including exhibition, meeting and office rooms
Boyacızade Konağı	Semi-Repaired	Restaurant including exhibition and dining rooms
Tahtacıörencik Village House	Non-Repaired/Original	Dwelling

Table II. Brief description wall and floor components examined in the study.

Wall Component	Room-to-room	Floor Component	Room-to-room	Structure
Reconstructed-Wall 1	Exhibition-Exhibition	Reconstructed-Floor 1	Meeting room- Exhibition	Ankara Bağ Evi
Semi-Repaired-Wall 2	Exhibition-Exhibition	Semi-Repaired-Floor 2	Exhibition-Exhibition	Boyacızade Konağı
Semi-Repaired-Wall 3	Exhibition-Exhibition	Semi-Repaired-Floor 3	Exhibition-Exhibition	Boyacızade Konağı
Original-Wall 4	Living room-Living room	Original-Floor 4	Living room-Entry	Tahtacıörencik Village House

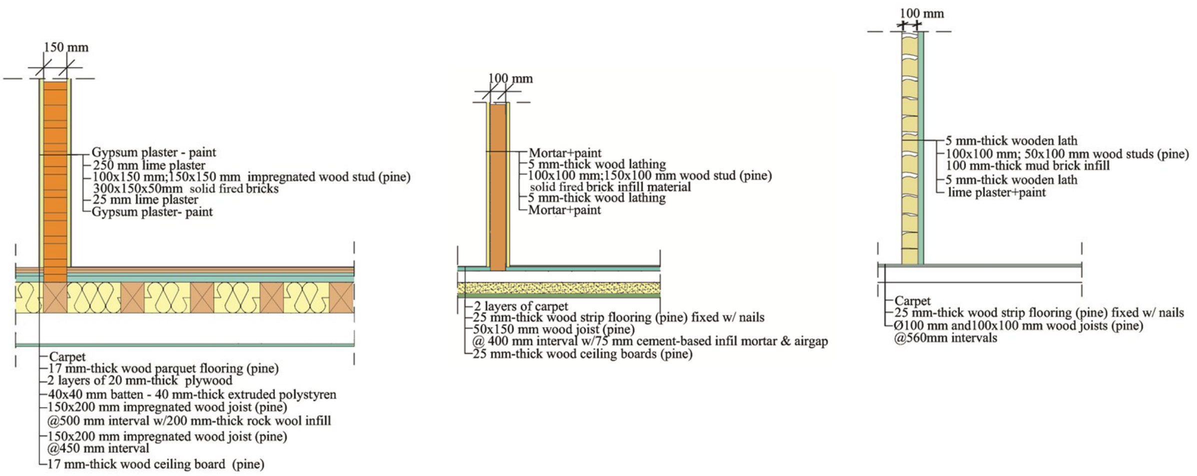

Figure 1. The configuration of existing walls and floors and definition of each layer forming the Reconstructed-Wall & Floor 1 (at the left); Semi-Repaired-Wall & Floor 2/3(at the middle); Original-Wall & Floor 4 (at the right).

3. Results and Discussion

The in-situ and simulated data were interpreted together in order to assess sound insulation performances of wall and floor components in non-repaired and repaired traditional timber-framed dwellings.

3.1. Sound Insulation Performance of Original Wall and Floor Sections

The in-situ R'w data of 26dB determined in the Original Wall-4 in Tahtacıörencik Village House have shown the poor sound reduction performance through the original configuration of the wall (Table III). That value is considerably below the acceptable minimum R'w value of 50dB required for dwellings [9]. Such a poor performance measured during the in-situ tests is attributed to the presence of door opening along the wall. Since no gaskets are used at the edges where the main frame and swing come together as well as poor sound insulation quality of the door swing, it seemed to be the weakest part of the wall. In such composite wall surfaces composed of wall section and opening units, the weakest surfaces are expected to act dominant during the in-situ measurements and to reduce the sound insulation capacity of the overall wall section drastically [10].

Table III. In-situ, simulated and calculated Rw data of Original-Wall 4 for its solid part (without an opening) and as a composite wall (composed of its solid part and opening).

AIRBORNE Sound Transmission					
Analyses	In-situ data	Simulated Data			Calculated data
		INSUL		BASTIAN	
Component	Solid wall+Opening	Solid wall	Solid wall + Opening	Solid wall	Solid wall + opening
Single number ratings	R'w (dB)	Rw (dB)	Rw (dB)	R'w (dB)	Rw (dB)
Original-Wall 4	26	42-44	28	28-35	29

Table IV. In-situ, simulated and calculated Rw and Lnw data of Original-Floor 4.

Analyses	AIRBORNE Sound Transmission			IMPACT Sound Transmission		
	In-situ data	Simulated data		In-situ data	Simulated data	
		INSUL	BASTIAN		INSUL	BASTIAN
Single number ratings	R'w (dB)	Rw (dB)	R'w (dB)	L'nw (dB)	Lnw (dB)	L'nw (dB)
Original-Floor 4 w/carpet	29	NA	NA	69	NA	NA
Original-Floor 4 w/out carpet	NA	32	28	NA	85	91

The INSUL analyses on the Original-Wall 4 have shown that the Rw values of its solid part (without any opening) were found to be in the range of 42-44dB while that Rw performance of the solid wall is reduced to 28dB in presence of the door (Table III). In short, simulated data has shown a decrease of 16dB in Rw performance of the wall due to the presence of door opening that supports the in-situ measurements.

The predicted Rw value of the Original-Wall 4 was found to be 29dB. The similarity of the calculated and simulated Rw values of Original-Wall 4 proved the dominant role of an opening in a wall section and the consistency between in-situ, simulated and calculated Rw values.

The BASTIAN analyses on the Original-Wall 4 have shown the presence and effect of flanking transmission through the wall component. The estimated R'w values in the range 28dB and 35dB presented that the effect of flanking increased the overall sound transmission through the wall component in the range of 6-16dB with an average increase of 11dB±4dB.

In short, the two factors which are "the presence of non-insulated door/window openings and air/sound leakages through their edges" and "the poor construction detailing which accelerates flanking sound transmission" are the main critical reasons, all of which are determined to reduce the overall sound insulation performance of the original wall component by around 16dB and 11dB, respectively.

The in-situ R'w and L'nw data obtained for the Original-Floor 4 have shown the insufficient impact and airborne sound insulation performance of the original configuration of floor. The

Original-Floor 4 fully-keeps its original the traditional construction techniques and authentic materials. Its in-situ R'w and L'nw performances with the values 29 dB and 69 dB (Table IV), respectively, exhibited that the sound reduction index is considerably below the acceptable minimum level of 50 dB while the impact sound level is not enough to conform the acceptable limit above 65dB [9].

The simulated Lnw data obtained by INSUL and BASTIAN analyses were estimated to be 85 dB and 91 dB, respectively (Table IV). Those values are 16-21 dB lower than in-situ Lnw data. One of the reasons of those better results showing the real impact sound insulation performance of the existing original floor can possibly be due to the presence of the carpet on floor surface. However, the contribution of the carpet to the impact sound level is expected to be 7-8 dB. Therefore, the noticeable and better performance of the original floor component may be attributed to the inherently-better density and durability characteristics of old timber in comparison to the lately-grown ones [11,12,13], as well as traditional construction detailing and techniques.

3.2. Sound Insulation Performance of Reconstructed/Repaired Wall and Floor Sections

The in-situ R'w data of 28 dB, 23 dB and 24 dB obtained for the Reconstructed-Wall 1 in Ankara Bağ Evi, Semi-Repaired-Wall 2 and Semi-Repaired-Wall 3 in Boyacızade Konağı, respectively, indicated the poor sound insulation performance of the renewed wall configurations. Their in-situ R'w data are considerably below the acceptable limit R'w value of 50 dB [9]. Such poor performances measured during the in-situ tests are attributed to the presence of the panelled doors along the walls. This is the same problem observed in the Original-Wall 4. Among them, Reconstructed-Wall 1 has slightly better sound reduction performance than Semi-Repaired-Wall 2 and Semi-Repaired-Wall 3 due to its thicker wall section.

The INSUL analyses on the existing walls with and without openings have shown that the Rw values of their solid parts (without any opening) were found to be in the range of 45-50 dB while those performances were reduced down to the range of 24-27 dB (Table V), respectively, in presence of the doors along the wall.

A similar decrease in their Rw performances was also determined, by the Equation 1 in the range of 19-20 dB [3]. The calculated and simulated Rw data which are similar with the in-situ performances of those walls proves the dominant role of an opening in a wall section and also presents the consistency between in-situ, simulated and calculated Rw values.

According to the BASTIAN analyses on the Reconstructed-Wall 1; Semi-Repaired-Wall 2 Semi-Repaired-Wall 3, their estimated R'w values in the ranges of 29-37dB, 28-38 dB and 29-36 dB, respectively, exhibited that the adverse effect of flanking increased the overall sound transmission through the wall component in the range of 13-21dB with an average of 16 dB, 7-17 dB with an average of 12 dB and 9-16 dB with an average of 12 dB, respectively (Table VI).

Similar to the Original-Wall 4, the two factors of "the presence of door openings" and "the poor construction detailing that accelerates flanking sound transmission" are the main critical reasons, all of which reduce the overall sound insulation performance through the existing walls in the ranges of 20-23dB and 12-16dB, respectively.

The in-situ R'w and L'nw data obtained for the Reconstructed-Floor 1, Semi-Repaired-Floor 2 and Semi-Repaired-Floor 3 have shown the insufficient impact and airborne sound insulation performance of those existing floors (Table VI). Their in-situ R'w performances with values of 45dB, 25dB and 37dB, respectively, and their in-situ L'nw performances with values of 68dB, 76dB and 77dB, respectively exhibited that the sound reduction indexes are considerably below the acceptable minimum level of 50dB while the impact sound level is not enough to satisfy the acceptable level above 65dB [9]. Their low sound insulation performances can be due to their insufficient insulation properties and the direct fixing of cladding boards to the structural timber elements without using any sound break. Due to the thicker cross section and higher surface density (kg/m^2) of Reconstructed-Floor 1, its airborne and impact sound insulation performances, expectedly, was found to be better than the others.

Although the Semi-Repaired-Floor 2 and 3 have the same floor section, the Floor 3 presented more resistivity to sound transmission than the Floor 2 with a difference of 12 dB in R'w value (Table V). There was a square-shaped hole with the sizes of approximately 10cmx10cm which is positioned in the Semi-Repaired-Floor 2 area and used for the run of heating system piping in vertical. Although the cavity is filled with a kind of wool sponge, it causes considerable sound transmission through the floor section.

The in-situ examination has shown that the presence of carpet provides an improvement of 7 dB in L'nw value and increases the impact sound resistance (Table VI).

According to the INSUL and BASTIAN simulation analyses, the estimated Rw and Lnw values obtained for the existing floor sections were found to be supporting the in-situ measurements. That proved the insufficiency of the existing floor section in terms of airborne sound insulation capacity as well as clarified the adverse effect of the hole located in the Semi-Repaired Floor 2, accelerating the sound transmission through its section. In addition, the comparison of INSUL and BASTIAN results has shown that the decrease of 5dB and 4dB in estimated Rw and Lnw values, respectively, signalled the adverse effect of flanking on the overall sound reduction performance of the Semi-Repaired-Floor 2/3.

Table V. In-situ, simulated and calculated Rw data of Reconstructed-Wall 1 and Semi-Repaired-Wall2/3 for their solid parts (without an opening) and as composite walls (composed of solid part and opening).

AIRBORNE sound transmission					
Analyses	In-situ data	Simulated data			Calculated data
		INSUL		BASTIAN	
Component	Solid wall + Opening	Solid wall	Solid wall + Opening	Solid wall	Solid wall + Opening
Single number ratings	R'w (dB)	Rw (dB)	Rw (dB)	R'w (dB)	Rw (dB)
Reconstructed-Wall 1	28	50	27	29-37	30
Semi-Repaired-Wall 2	23	45	24	28-38	24
Semi-Repaired-Wall 3	24	45	25	29-36	26

Table VI. In-situ, simulated and calculated Rw and Lnw data of Reconstructed-Floor 1 and Semi-Repaired-Floor 2/3.

Analyses	AIRBORNE sound transmission			IMPACT sound transmission		
	In-situ data	Simulated data		In-situ data	Simulated data	
		INSUL	BASTIAN		INSUL	BASTIAN
Single number ratings	R'w (dB)	Rw (dB)	R'w (dB)	L'nw (dB)	Lnw (dB)	L'nw (dB)
Reconstructed-Floor 1 w/carpet	47	NA	NA	68	NA	NA
Reconstructed-Floor1 w/out carpet	NA	46	NA	75	74	NA
Semi-Repaired Floor 2 w/carpet	25	NA	NA	76	NA	NA
Semi-Repaired Floor 2 w/out carpet	NA	39	34	NA	76	80
Semi-Repaired Floor 3 w/carpet	37	NA	NA	77	NA	NA
Semi-Repaired Floor 3 w/ out carpet	NA	39	35	NA	76	80

4. Conclusions

The sound insulation performances of timber framed wall and floor components examined in the study, both repaired and non-repaired ones, were found to be insufficient due to their Rw values below widely accepted limit of 50dB and Lnw values above 65dB.

The presence of door/window openings, air leakages through the edges of openings and direct fixing any cladding layers to the structural elements are the main reasons that reduce the overall sound insulation performance of the wall and floor components. In case that air/sound leakages through the wall and floor components are eliminated by using stoppers, sealants, gaskets, mud or board fillers and the existing openings are replaced with the solid core/insulated door or insulated window components, a significant improvement is expected to have been achieved in their sound reduction performances. The flanking sound transmission through the wall and floor sections can be controlled by using sound breaks that separate cladding layers from wall/floor structure, therefore that provide discontinuity between the layers.

There is the necessity of keeping the inherent/authentic features of original wall and floor components. Therefore, "if necessary, only minimum intervention" should be permitted.

The sound insulation performances of reconstructed or renewed wall and floor components in timber-framed dwellings need to be designed/improved in case of refunctioning of those structures. For instances: in offices, the floors is required to provide Rw and Lnw performances above 52 dB and below 53 dB, respectively; in classrooms, the floors should provide Rw and Lnw values above 55 dB and below 53 dB; for the floors between workshop room and classroom, the Rw and Lnw performances are expected to be above 55 dB and below 46 dB, respectively [3]. For the walls, Rw performance above 50-52 dB are acceptable for the walls of offices, above 55-57 dB for the walls of private offices/meeting rooms, above 60 dB for the walls of a classroom [14]. In such cases, demountable attachments by using dry construction techniques and by including sound absorbing infill and sound breaks within the attached wall/floor section are suggested to improve airborne and impact insulation of reconstructed or renewed traditional timber frame wall and floor sections.

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References

[1] ISO 140-4:1998.Measurement of Sound Insulation in Buildings and Building elements- Part 4: Field Measurement of Airborne Sound Insulation between Rooms, Switzerland, 2013.

[2] ISO 140-7:1998.Measurement of Sound Insulation in Buildings and Building Elements- Part 4: Field Measurement of Impact Sound Insulation between Rooms, Switzerland, 2013.

[3] M. Eckard, B. Müller: Acoustics and Sound Insulation, Detail Practice. GBH& Co. KG, Munich, 2009.

[4] H. Hauben, H. Guillaud: Earth Construction: A Comprehensive Guide. Intermediate Technology Publications, London, 1994.

[5] I.Meric, M. Erdil, N. Madani, B. Alam. A., Tavukcuoglu, E.N. Caner Saltik: Technological properties of earthen building materials in traditional timber frame structures. Proc. Kerpic'13,465-473.

[6] A. Kandemir: Soundness Assessment of Historic Structural Timber by Use of Non-Destructive Methods, Master Thesis. METU, Ankara, 2010.

[7] ISO 717-1:2013. Acoustics -Rating of Sound Insulation in Buildings and of Building Elements-Part1:Airborne Sound Insulation, Switzerland, 2013.

[8] ISO 717-2:2013. Acoustics-Rating of Sound Insulation in Buildings and of Building Elements-Part 2: Impact Sound Insulation, Switzerland, 2013.

[9] B. Ingelaere: Acoustic Design of Lightweight Timber Frame Constructions. COST Action FP0702, Chapter 1-2, Building Research Institute, Belgium, Brussels, 2012.

[10] M. D. Egan: Architectural Acoustics. McGraw-Hill, New York, 1988.

[11] M. Long: Architectural Acoustics. Elsevier/Academic Press, Boston, 2006.

[12] A. Kandemir-Yucel, A. Tavukcuoglu, E.N. Caner-Saltik: In situ Assessment of Structural Timber Elements of a Historic Building by Infrared Thermography and Ultrasonic Velocity. Infrared Physics & Technology 49 (2007) 243–248.

[13] B. Ridout: Timber Decay in Buildings: The Conservation Approach to Treatment. E&FN Spon, New York, 2000.

[14] D. Littlefield: Metric handbook: Planning and design data. Routlege, 2015.