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The development of the EN 12354 series: 1989-2009

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ABSTRACT
The development of the building acoustic prediction models in EN 12354 started twenty years ago, since the CPD made it necessary within Europe to link the acoustic performance of building products and elements to the performance of buildings. It concerned six acoustic aspects: airborne sound insulation, impact sound insulation, façade insulation, sound radiation to the outside, sound due to service equipment and reverberant sound in enclosed spaces. So these became the six parts of the standard, drafted by working group 2 of CEN Technical Committee 126 'Building Acoustics'. For various building elements the product quantities and their measurement methods were well established so these could be used as input to the prediction (estimation) of the building performance. But drafting these prediction models made clear what type of input data was still missing and what type of product quantities and measurement methods should be added. This generated activities in other working groups to define methods and in various countries to collect the product performances appropriate for the local building situations. An overview will be presented of these developments so far and the items still to be covered or improved.

1. INTRODUCTION
More than twenty years ago architects and builders relied mainly on experience in building houses and other buildings. Based on trial-and-error they managed to build houses fulfilling the requirements like those on the sound reduction between dwellings. However, every time building materials and methods changed or requirements were made more stringent it took a while, with many errors, before experience has adjusted to the new situation. In other industries like the car industry these habits had long been passed and predicting performance in the design stage and adjusting designs to fulfill requirements was already very common. Yet research was going on in several – mainly European – countries in order to be able to predict sound transmission in buildings.

A big boost to derive common prediction models came from the EU, the establishment of the Construction Product Directive[1] in 1989. In order to enhance trade within the EU this Directive stated that free trade shall be possible for construction products with a certain performance, as indicated by the CE-marking, fit to erect buildings that fulfill essential requirements. One of these requirements is 'protection against noise' and in so-called interpretative documents it was later specified that this concerns airborne sound between rooms, impact sound between rooms, sound reduction by the façade, sound radiation by a façade to the outside, sound due to service equipment and reverberant sound in common spaces. For the building performance for these items measurement methods should be established. Also for all building products involved in these items the acoustic performance should be established through standardized measurement methods. All these standards could to a large extent be based on existing ISO standards, extending and renewing them as far as

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necessary for the European needs. But completely missing was an agreed way to link the product performance to the building performance. Due to the formulation in the CPD it was necessary to create this link. This was especially felt by Germany since their method to create this link for airborne sound insulation, measuring separating elements with a specified amount of flanking transmission – bauübliche Nebenwegen – was no longer possible since it was already agreed to measure the performance of building elements without flanking transmission.

In order to create all the necessary standards for the CPD, Technical Committee 126 'Building Acoustics' was established already in May 1988 in Paris with four Working Groups at that time: WG1 for insulation and absorption laboratory measurement methods, WG2 for the link between acoustic performance of products and building performance, WG3 for laboratory measurements of water supply systems and appendages and WG4 to create a more unified system for rating the insulation performance. WG2 started to work on a standard that became EN 12354[2] with six parts covering all the specified essential acoustic requirements.

2. HISTORY OF EN 12354

WG2 was established in 1988 and had its first meeting in November 1989 in Bellaria (Italy), now twenty years ago. Since than there have been 22 meetings and 6 ad-hoc group meetings on various aspects. The ad-hoc group on lightweight is still active, though actually the COST action on lightweight timber based buildings[3] currently provides the best platform to develop and improve EN 12354 towards lightweight building structures. Figure 1 illustrates all the places in Europe were meetings have taken place over the last 20 years.

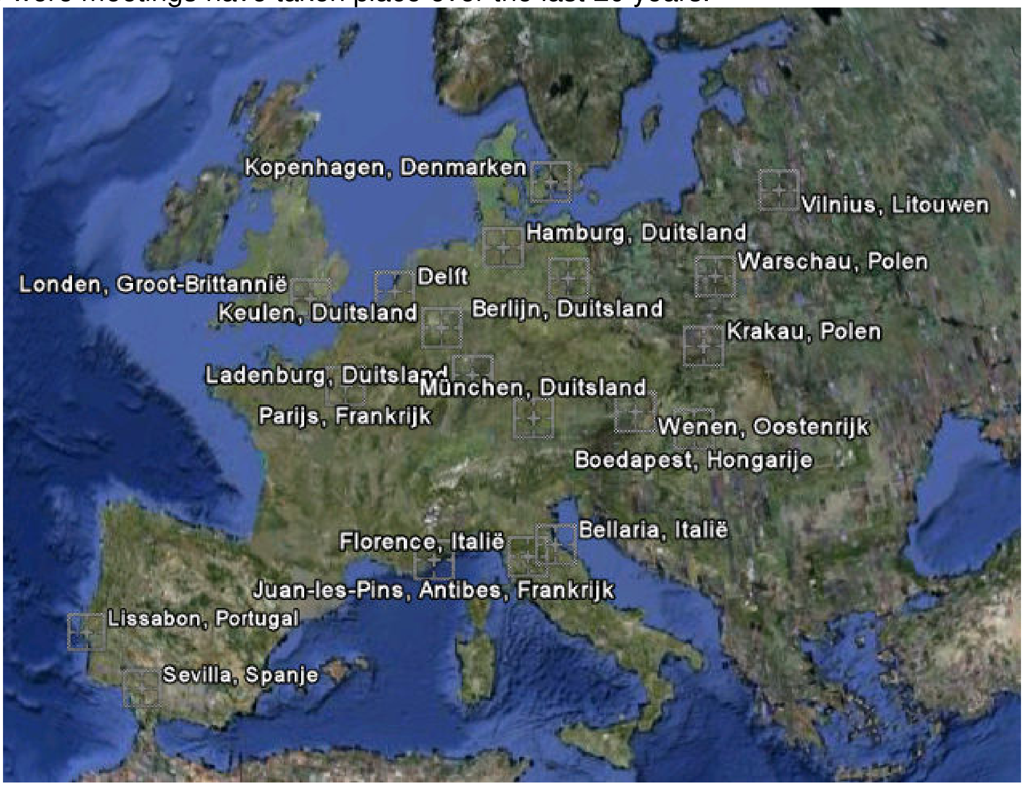

Figure 1: Illustration of airborne and impact sound transmission path with relevant quantities.

Though WG2 has about 25 members, on average 15 members were present on meetings so spending together an estimated total of € 1.000.000,-, including travelling cost and time, preparation and some homework at an hour rate of € 100,-. Including the initial drafting of documents, the secretarial cost at AFNOR and the cost of all national bodies preparing comments to the proposals, the cost per part will be at least € 200.000,- (and all that information is sold for something like € 60,- to € 90,-). At the start of the activities the European Commission provided through their mandate for the first four parts a contribution of 12.750 ECU, being the equivalent to the Euro, so about 7%. So far some general background and numbers, now to the content.

A. Airborne and impact sound insulation

EN 12354-1 & 2[2] deal with the prediction of airborne and impact sound insulation between rooms. The work started with applying the available models and guidelines to some typical building situations covering the variation in construction methods in Europe. Since most of these models were empirical the outcome was clear: most models worked reasonably for known building constructions but clearly not for unknown types as were normal in other countries. So it was decided to develop a model that was based on physics but simple enough to be applied on an engineering level. This could be based largely on earlier research, at least for more or less homogeneous structures[4]. The sound transmission between rooms is divided in the transmission by different transmission paths; see figure 2. For each path the transmission of sound power is considered. Though originally derived in a different way, this approach is essentially equal to a SEA-modelling of the sound transmission[5]. But instead of typical SEA quantities, the model uses well-known quantities as the sound reduction index R of all involved building elements and the normalized impact sound pressure level L_n of floors as measured through ISO 140-3 and -6[6].

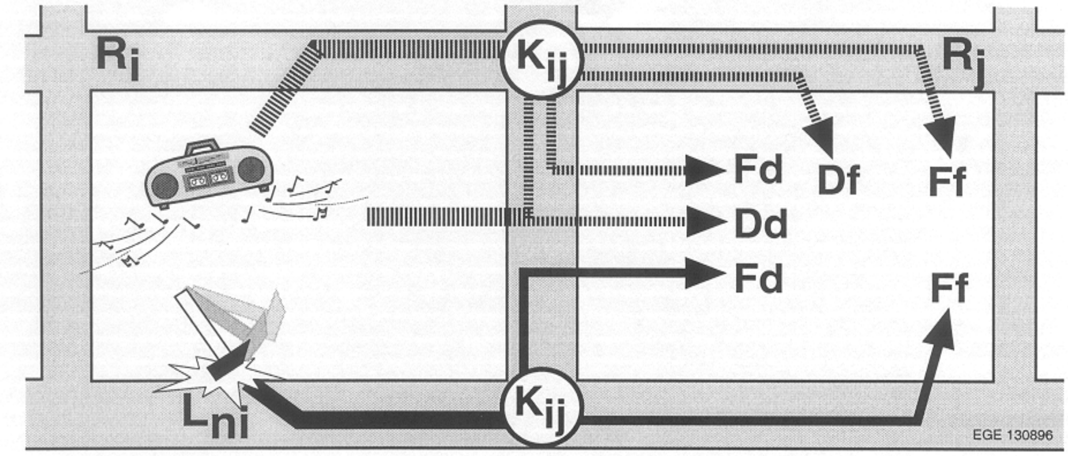

Figure 2: Illustration of airborne and impact sound transmission path with relevant quantities.

In its most simple form the flanking sound reduction index R_{ij} and the normalized impact level $L_{n,ij}$ for transmission path ij can be written as in eq. 1 and 2.

$$R_{ij} = \frac{R_i + R_j}{2} + \Delta R_i + \Delta R_j + K_{ij} + 10\lg\frac{S_s}{l_{ij}} \qquad (1)$$

$$L_{n,ij} = L_{n,ii} - \Delta L_i - \Delta R_j + \frac{R_i - R_j}{2} - K_{ij} - 10\lg\frac{S_i}{l_{ij}} \qquad (2)$$

While for floor coverings and floating floors a method to measure the improvements is available (ΔL, ISO 140-8[6]), this was clearly missing for linings and suspended ceilings (ΔR). Hence this work item was added resulting in a draft for ISO 140 part 17[6]. However, the main missing aspect was the performance of junctions between building elements. A new quantity was defined, vibration reduction index K_{ij}, and a measurement standard established ISO 10848[7]. This standard than also covered the measurement of the total flanking transmission by element combinations, including suspended ceilings and raised floors, formally treated in some of the ISO 140 parts. The remaining parameters follow form the dimensions of the considered situation (junction length l_{ij}, area of the separating element S_s and the area of the excited element S_i) .

The complete model is somewhat more complex and takes into account the structural reverberation time of the elements involved in the field. This also restarted the discussion on taking this into account for heavier building elements in the laboratory, to facilitate predictions and to reduce the influence of the laboratory properties. But this discussion has not been finalized yet.

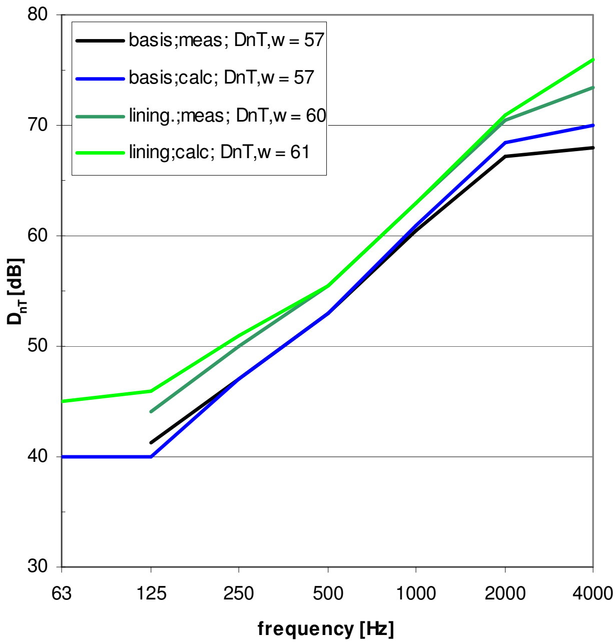

Figure 3: Measured and calculated sound level differences between living rooms; illustration of effect of an acoustic lining (ΔR_w =16 dB).

Figure 3 illustrates some prediction results in comparison with measurements for the sound reduction between rooms with a separating brick wall of 465 kg/m^2. Both measurement and prediction result in $D_{nT,w}$ = 57 dB. To improve the situation an acoustic lining is applied at one side of the wall; this lining showed an improvement of ΔR_w = 16 dB in the laboratory. Both measurement and prediction show only an improvement of about 3 dB in the actual field situation, clearly showing the importance of models to establish the flanking transmission.

B. Façade insulation and radiation

In EN 12354-3 & 4[2] the sound transmission through facades is treated, either to protect against outdoor noise (mainly traffic noise) or to protect the outside against radiated noise (workplaces, disco's etc.). These parts are based mainly on well-known theories, the main discussions were on what to consider as element: for instance the window as a whole or the composing parts like the glass, the frame and the sealing. Finally both approaches were covered by the standard. Since in various countries the requirements are specified quite different, the prediction result has to reflect this too. Often the requirements consider the sound reduction index of the façade, R_{facade}, or the overall normalized level difference, $D_{2m,nT}$, or even the indoor level. These are of course all related and two of these are presented in eq. 3a and 3b for a façade composed from N elements with area S_j in a façade with a total area of S in front of a room with volume V.

$$R_{facade} = -10\lg \sum_{j=1}^{N} 10^{-R_{part,j}/10}$$

$$R_{part} = R_j + 10\lg \frac{S}{S_j} \quad \text{or} \quad R_{part} = D_{ne,j} + 10\lg \frac{S}{A_o} \tag{3a}$$

$$D_{2m,nT} = R_{\text{facade}} + 10\lg \frac{0{,}16V}{T_o S} + \Delta L_{fs} \tag{3b}$$

For many building elements as applied in facades measurement methods are available for the element performance R, (ISO 140-3[5]) and D_{ne} (ISO 140-10[5]). Problems might arise with large elements for which no representative version can be tested in the laboratory test opening; there dedicated field measurements in selected situations can be helpful. Missing are standards to characterize sealing of slits, though such measurements can be based on the existing methods. Proposals to add this to the laboratory measurement standards are currently discussed.

Another important element for façade sound reduction can be the influence of the façade shape, the presence of balconies and such (ΔL_{fs}); see figure 4. However, it is not likely that a general measurement method can be established for this aspect. The data in the standard can best be extended by results of research or be replaced by a future engineering prediction method for these effects. One of the input data then needed, will be the absorption of elements and surface treatments for which a standard is available[8].

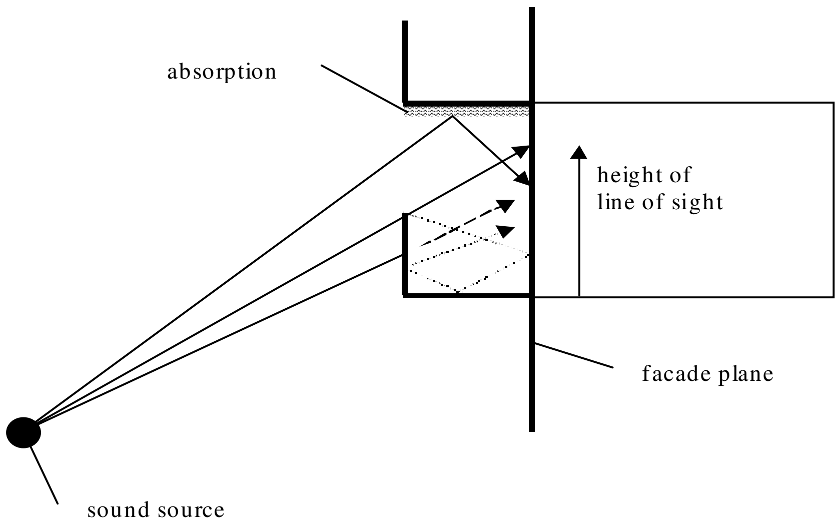

Figure 4: Illustration of the effects (screening, reflections) of balconies on the sound transmission through a facade.

Part 4 actually deals only with the façade itself and thus gives no direct answers to outdoor sound levels. Both the estimation of the inside sound levels as caused by the sound sources as the sound propagation outdoors are outside the scope of the standard and should be dealt with by other prediction models, as in ISO 9613[9]. Just to be helpful an informative annex gives a complete prediction model for the sound level outside for very simple situations.

C. Service equipment

The most complicated part of the series is EN 12354-5[2] for sound levels due to service equipment in buildings. This is partly caused by the large variety of equipment concerned and the various mechanisms of sound generation and propagation. The standard has to deal with sound propagation through ducts and pipes, airborne sound as radiated from sources and structure-borne sound form sources, where it must be realized the each equipment or installation can be composed of many sources. A lot is already known and studied concerning the first item[10] and the second item can largely be based on available knowledge, but there is a huge lack of practical research results concerning the last parts[11].

Though some measurement methods for elements existed[12,13], an overall scheme was missing in which the various elements and quantities used could find a logical place. This was therefore the first objective for part 5 of EN 12345: to create a general framework. For structure-borne sound the transmission through the building starts with the injected sound power by the source, applying the transmission as described in parts 1 and 2. The injected power by the installed equipment, $L_{Ws,installed}$, follows from characteristics sound power $L_{Ws,c}$ for the source and a coupling term D_C including the appropriate source and building properties; see figure 5. For the time being various methods can be used to deduce those source properties, as indicated in annexes of the standard. Hopefully in due time the measurement methods for sources will show a more direct link to these quantities. Indeed, the development of EN 12354 has triggered already a lot of research activities, also leading to new measurement standards for equipment noise, as relevant for heavy building structures[14]. But a lot of questions are still to be solved.

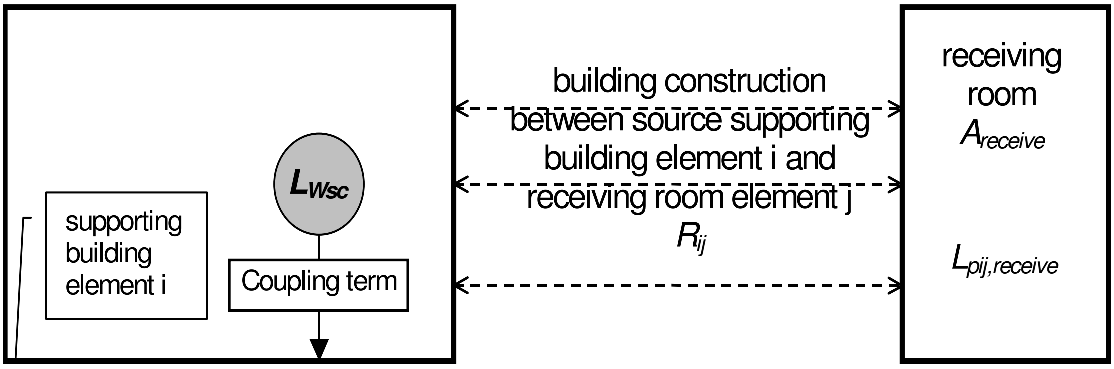

Figure 5: Illustration of parameters for the structure-borne sound transmission from a source to a receiver room.

The normalized sound level due to transmission of structure-borne sound via path ij, $L_{n,s,ij}$, normalized to an absorption area of A_{ref} = 10 m^2, follows from eq. 4

$$L_{n,s,ij} = L_{Ws,installed,i} - D_{sa,i} - R_{ij,ref} - 10\lg\frac{S_i}{S_{ref}} - 10\lg\frac{A_{ref}}{4} \qquad (4)$$

As stated the transmission is characterised by the flanking sound reduction index R_{ij}, but since the separating elements is not well defined in this case, the area of the separating element is replaced by a reference area S_{ref} = 10 m^2. Though we are considering structure-borne sound excitation on element i here, the transmission is actually the same for airborne and structure-borne sound, hence the use of the sound reduction index also here and adding a transfer function D_{sa}, relating the injected structure-borne sound power to an equivalent airborne sound power. This quantity is only depending on the properties of the excited element.

As stated the source strength for structure-borne sound is expressed in the characteristics sound power $L_{Ws,c}$, which is about the maximum power that source could inject in a building element. The actual injected power is specified by the coupling term which in its simplest form contains the mobility's of the considered element, Y_i, and the considered source Y_s; see eq. 5a and 5b.

$$L_{Ws,installed} = L_{W,sc} - D_C \tag{5a}$$

$$D_C = 10\lg\frac{|Y_s + Y_r|^2}{|Y_s|\operatorname{Re}(Y_r)} \tag{5b}$$

$$L_{Ws,installed} = L_F + 10\lg\operatorname{Re}(Y_r) \tag{5c}$$

In case the source could be considered as a force source, with force level L_F, this reduces to the well-known eq.5c. Figure 6 gives some examples for this situation of the force level of various sources. These equations are valid for a single point connection; in the normal case of several contact points the mobility's are to be considered as equivalent mobility's.

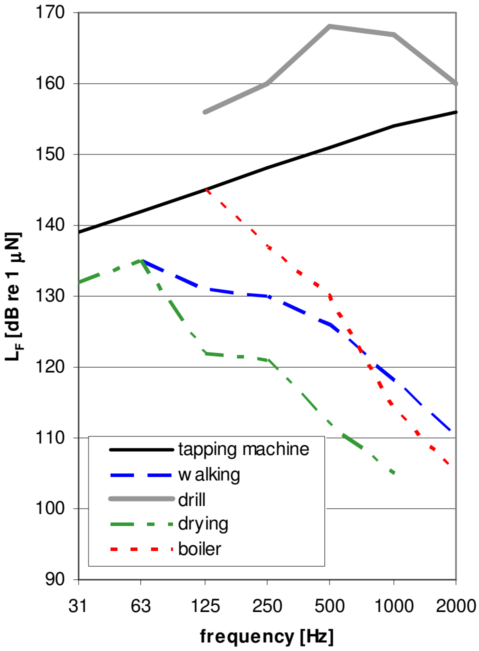

Figure 6: Force level for various structure-borne sound sources including the ISO tapping machine.

D. Reverberant sound

As is normal practice, EN 12354-6[2] used Sabine's relation to link reverberation time T to absorption data for building elements, α_s, and objects, A_{obj}, as determined by ISO 3548, see eq. 6. V is the volume of the space and S_i the wall area with given absorption coefficient. Especially for the use in larger or occupied spaces, attention is given to the actual empty volume to be used and the effect of attenuation in the air, which can normally be neglected for rooms say below 200 m^3.

$$A = \sum_{i=1}^{n} \alpha_{s,i} S_i + \sum_{j=1}^{o} A_{obj,j} \qquad T = 0{,}16\frac{V}{A} \tag{6}$$

However, the main problem is that for various enclosed spaces the Sabine-relation is not really adequate since the sound field is far from diffuse or the absorption is rather localized, for instance only the ceiling. To indicate at least possible deviations from the Sabine results an informative annex is included with a more detailed prediction model[15,16]. The effects are illustrated in figure 7, giving for a large room with absorbing ceiling and some scattering objects, the reverberation curve and time according to Sabine (S) and the estimation (3D) according to the annex of the standard. This certainly will not be the last answer, but at least a good indication of possible effects. Probably even more important for the reliability of predictions is the fact that the uncertainty in the input data as deduced from ISO 354[8] is still rather large.

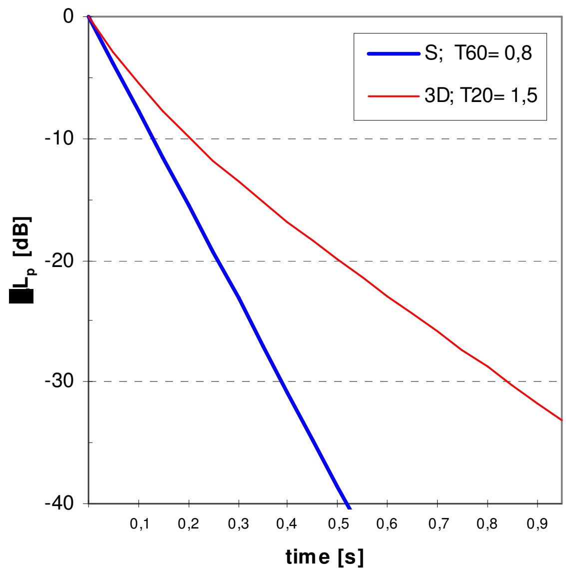

Figure 7: Calculated reverberation curves and times according to Sabine (S) and the estimation (3D) according to annex D of EN 12354-6.

3. CURRENT DEVELOPEMENTS AROUND EN 12354

The prediction models of part 1 and 2 of EN 12354 have been used quite extensively over the last years and have shown to be very useful, at least for buildings with mainly homogeneous structures. This is also reflected in several papers on the subject during this congress. A point of concern has been to best way to apply the methods for lightweight building structures. How to interpret the equations? How to adjust or extent them? How to collect the relevant input data? Including lightweight homogeneous elements is no real problem; in that case it is only necessary to derive the sound reduction index for resonant transmission from the measured vales including forced transmission. Proposals how to do that have been done[17,18]. More problematic is the situation with highly damped elements and layered elements. Fortunately a lot of research is going on in this area which should make it possible to extend and adjust EN 12354-1&2 as well as ISO 10848 in the near future in order to cover also light weight structures[19,20].

For the prediction of sound levels due to service equipment in buildings only the first draft of the standard EN 12354-5 is available. It is clear that this standard needs to be extended, adjusted and improved while gaining more practical knowledge on the subject in the future. To that extent research[21,22] is going on. There are also necessary contributions to improve measurement methods to characterize sources and other equipment parts. The most challenging aspect is the combination of equipment and light weight building structures[23,24].

4. CONCLUSIONS

Developing prediction models for the acoustic performance of buildings was triggered by the creation of the free market within Europe, but the need for such models was also felt in Europe and elsewhere to be able to erect buildings with new methods and materials and improved performance which can no longer be achieved with the 'trial-and-error' approach, so common for the construction industry.

However, to be able to predict the building performance it is necessary to have data on the performance of all building elements involved. Drafting the prediction models made clear that indeed measurement standards were available for some elements, but needed adjustment for others or were just simply missing. Hence activities were also started to develop or improve all standards that could produce the necessary input data for predictions.

Current activities focus on extending and improving the prediction by EN 12354 1&2 for lightweight building structures, hopefully leading to a renewed version of those documents within a few years. The newest part, EN 12354-5 for service equipment noise, also needs further development based on experience with its application and the further development of measurement standards for sources and system elements, to provide the correct input data.

ACKNOWLEDGMENTS

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