TAP2 - PAT2

PROGRAMME TO STIMULATE
KNOWLEDGE TRANSFER
IN AREAS OF STRATEGIC IMPORTANCE

Towards an Integrated Acoustic and Thermal Approach in Buildings

TIATAB

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PROGRAM TO STIMULATE KNOWLEDGE TRANSFER IN AREAS OF STRATEGIC IMPORTANCE

TAP2

FINAL REPORT

TOWARDS AN INTEGRATED ACOUSTIC AND THERMAL APPROACH IN BUILDINGS

TIATAB

P2/00/09

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1. Summary – Résumé - Samenvatting

1. A. SUMMARY

Context

Energy saving and thermal insulation get a lot of attention these days. And this is indeed justified and most necessary to cope with the challenges of climate change and rising energy costs. Unfortunately, the major focus on thermal insulation very often results in neglecting the acoustic aspects and leads to major problems: being able to isolate oneself for privacy reasons or as a protection against neighbour or environmental noise is a basic need and no user of a building accepts that lack of acoustic comfort. Building elements, equipment and the building itself should be designed taking in account thermal AND acoustic considerations (and of course all other requirements). An integrated approach is difficult for it requires know how in both disciplines.

Goals

The overall goal is to provoke a change from almost “monodimensional” thermal thinking to an integrated thermal AND acoustic approach in construction. The project had the following ambitions:

- *To get know-how about an integrated approach so as to be able to innovate and find optimized solutions;*
- *To realize software tools that will help the designer to integrate both acoustic and thermal considerations into an optimized design. Originally (subsidy request) the objective was to create acoustic modules and to attach them to the DECISYS EPR-software. During the project, a more ambitious goal was set to create acoustic and thermal simulation software that is attached to basic BIM modellers (REVIT, etc.). The objective was to advance as far as possible with the idea of the thermal and acoustic BIM equivalent of a “spelling checker” of text treatment programs;*
- *To create databases and as such force the industry to declare the performances of their products and to improve and innovate them (as an easy comparison with competing products will certainly require). In a later phase, links with the BIM modeller were established;*
- *To generate guidelines for optimized thermal and acoustic solutions (and allowing as such for innovative products, building elements and buildings).*

Main results and conclusions

Three main axes were developed during the research project:

1) An Atlas of integrated building details was created:

The Atlas of Integrated Building Details offers robust solutions that comply with thermal and acoustic requirements and translate the original requirements in more “understandable requirements” such as surface mass, distances, etc. The Atlas explains equally the degrees

of liberty one has to modify the presented details without losing acoustic or thermal performances, specifies attention points in the project and execution phase and explains how everything acoustically works. The Atlas of Building Details exists on paper yet only as an internal research document that is given to BELSPO as one of the research deliverables. Part of the information will be published in several articles by BBRI. The complete information will also be published on the “Normen Antennes” website (expected spring 2011) and under the form of a special Technical Note of the BBRI that will be edited under the form of ring binders. The idea is *to continue to complete* these robust details with any new integrated solutions or concepts that comply with the thermal and acoustic requirements. The obtained research information is now being continuously used in all conferences, technical publications by third parties and forms a basis of responses to comply with the new requirements of NBN S 01-400-1:2008 “Criteria for acoustic comfort in dwellings”.

2) Integrated acoustical and thermal prediction software tools were created that can function in a BIM environment

The principle of Building Information Models (BIM) is that it does not only contain geometrical data (visualised by a 3D-model), but all kind of technical data that can be added throughout the design process and life of the building. It can contain attributions of all interveners in its design (architects, consulting engineers, contractors,…). A fully workable program was developed that can predict thermal performances and the façade sound insulation of a Building Information Model. This program can communicate with the Tiatab database and extract directly technical information (see next point). A main conclusion of the research program is that working with BIM is the future. This evolution is of utmost importance for building element manufacturers (e.g. technical documentation), architects and contractors. Using BIM allows generating a complete virtual building and to evaluate future performances and avoid as such possible problems.

3) Integrated databases were created on the internet that can be consulted by the BIM software

The availability of acoustic and thermal data of building elements is a necessity in this integrated approach. This information is necessary to estimate the overall performance and to be able to apply correct building details in the project. Nowadays it is a difficult task to obtain this information: sometimes one can find data about the thermal performances on the website or technical documentation of the producer, but then very often the acoustic information is missing. And vice versa: for building elements with specific acoustic applications, the thermal information will sometimes be missing. Very often the data is missing because it simply hasn’t been measured. And that’s very often an indication that the manufacturer has not been thinking about this integrated approach. A web database was created that communicates with BIM-applications and stores technical data such as acoustic, thermal, fire, etc. characteristics. It contains search engines and can be filled in by manufacturers themselves after applying for a password. It is available on the internet on www.tiatab.be. Generic data (independent of manufacturers) were calculated (using new prediction tools developed during the research project) and stored in the database. Work on the database will be continued: it has international ambitions (too much work for the manufacturers to enter the data only for Belgium) and will be promoted during the European COST ACTION TU0901.

1. B. RÉSUMÉ

Contexte

Les économies d'énergie et l'isolation thermique font actuellement l'objet de toute l'attention; une attention bien justifiée et tout à fait nécessaire si l'on veut relever les défis du changement climatique et de la hausse des coûts de l'énergie. Malheureusement, l'accent mis essentiellement sur l'isolation thermique a souvent pour effet de négliger les aspects acoustiques, et entraîne de graves problèmes: la possibilité de s'isoler pour des raisons d'intimité ou pour se protéger du bruit de voisinage ou du bruit ambiant est un besoin fondamental, et aucun utilisateur de bâtiment n'accepte ce manque de confort acoustique. La conception des éléments de construction, des équipements et du bâtiment proprement dit doit tenir compte de considérations thermiques ET acoustiques (outre, bien sûr, toutes les autres exigences). Une approche intégrée est difficile car elle nécessite un savoir-faire dans les deux disciplines.

Objectifs

L'objectif global est de provoquer un changement de mentalité, et de passer d'une pensée quasiment "unique" thermique à une approche intégrée thermique ET acoustique dans la construction. Le projet poursuivait les ambitions suivantes:

- *Acquérir un know-how concernant une approche intégrée, de manière à pouvoir innover et trouver des solutions optimisées;*
- *Réaliser des outils logiciels qui aideront le concepteur à intégrer des considérations à la fois acoustiques et thermiques dans un projet optimisé. A l'origine (demande subsidiaire), l'objectif était de créer des modules acoustiques et de les rattacher au logiciel DECISYS EPR. En cours de projet, un objectif plus ambitieux a été défini: il s'agissait de créer un logiciel de simulation acoustique et thermique rattaché à des modélisations BIM basiques (Building Information Models comme réalisable par REVIT, etc.). L'objectif était d'avancer le plus loin possible dans l'idée de l'équivalent, en termes de BIM thermique et acoustique, d'un "correcteur orthographique" ou des programmes de traitement de texte;*
- *Créer des bases de données et forcer de ce fait les fabricants à déclarer les performances de leurs produits, à les améliorer et à innover (ce à quoi une comparaison aisée avec des produits concurrents les forcera certainement). A un stade ultérieur, des liens avec la BIM ont été établis;*
- *Générer des directives pour des solutions thermiques et acoustiques optimisées (et permettant de ce fait l'innovation dans les produits, les éléments de construction et les bâtiments).*

Principaux résultats et conclusions

Trois grands axes ont été développés durant le projet de recherche:

1) Un Atlas des détails intégrés d'un bâtiment a été créé:

L' “Atlas of Integrated Building Details“ offre des solutions robustes qui répondent aux exigences thermiques et acoustiques, et traduisent les exigences initiales en “exigences plus compréhensibles“, telles que la masse superficielle, les distances, etc. L'Atlas explique également les degrés de liberté qu'on a de modifier les détails proposés sans perte au niveau des performances acoustiques ou thermiques, il spécifie des points d'attention dans la phase de projet et d'exécution, et explique comment tout fonctionne sur le plan acoustique. L' “Atlas of Building Details“ existe sur papier mais uniquement en tant que document interne de recherche remis à BELSPO en tant qu'un des produits livrables de la recherche. Une partie des informations seront publiées dans une série d'articles par le CSTC. Les informations complètes seront également publiées sur le site web des “Antennes Normes Acoustique” (normalement au printemps 2011) et imprimées sous la forme d'une Note d'information technique spéciale du CSTC, qui sera éditée dans des classeurs à anneaux. L'idée est de *continuer à compléter* ces détails robustes avec l'ensemble des solutions ou concepts intégrés nouveaux qui répondent aux exigences thermiques et acoustiques. Les informations fournies par la recherche sont actuellement utilisées en continu dans toutes sortes de conférences et de publications techniques de tierces parties; elles constituent une base de départ pour observer les nouvelles exigences de la NBN S 01-400-1:2008 "Critères acoustiques pour les immeubles d'habitation".

2) Des outils logiciels de prédiction intégrée acoustique et thermique ont été créés et peuvent fonctionner dans un environnement BIM

Le principe de la Modélisation des Données d'un Bâtiment (BIM) est qu'elle ne contient pas uniquement des données géométriques (visualisées par un modèle 3D) mais toutes sortes de données techniques qui peuvent venir s'ajouter tout au long du processus de conception et de la vie du bâtiment. Elle peut contenir les attributions de tous les intervenants dans sa conception (architectes, ingénieurs-conseils, entrepreneurs, …). Un programme totalement exploitable, développé pendant la recherche, s’intègre dans le modèle BIM et peut prédire les performances thermiques et l'isolement acoustique des façades des bâtiments. Il peut communiquer avec la base de données Tiatab et en extraire directement des informations techniques (voir point suivant). Une des principales conclusions du programme de recherche est que l'avenir est au travail avec la BIM. Cette évolution revêt une importance capitale pour les fabricants d'éléments de construction (p.ex. pour leur documentation technique), les architectes et les entrepreneurs. Le recours à la BIM permet de générer un bâtiment virtuel complet, d'en évaluer et d’optimaliser les futures performances et d'éviter ainsi les problèmes éventuels.

3) Des bases de données intégrées ont été créées sur l'internet et peuvent être consultées par le logiciel BIM.

Dans le cadre de cette approche intégrée, il est indispensable de disposer des données acoustiques et thermiques des éléments de construction. Ces informations sont nécessaires pour estimer la performance globale et appliquer des détails corrects dans le projet. Or, ces informations sont difficiles à obtenir à l'heure actuelle: si l'on trouve parfois des données concernant les performances thermiques sur le site web ou dans la documentation technique du producteur, les informations acoustiques font très souvent défaut. Et inversement: les informations thermiques manquent parfois à propos d'éléments de construction destinés spécifiquement à des applications acoustiques. Très souvent, ces données manquent tout simplement parce qu'elles n'ont pas été mesurées. Et c'est généralement une indication que le fabricant n'a pas réfléchi à cette approche intégrée. Une base de données créée sur l'internet communique avec les applications BIM et enregistre des données techniques telles que les caractéristiques acoustiques, thermiques, de comportement au feu, etc. Elle contient des moteurs de recherche et peut être alimentée par les fabricants eux-mêmes après introduction d'un mot de passe. Elle est accessible sur l'internet à l'adresse www.tiatab.be. Des données génériques (indépendantes des fabricants) ont été calculées (à l'aide d'outils de prédiction mis au point pendant le projet de recherche) et stockées dans la base de données. Le travail sur la base de données va se poursuivre: elle a des ambitions internationales (l'introduction des données uniquement pour la Belgique serait un travail trop lourd pour les fabricants) et fera l'objet d'une promotion dans le cadre du programme européen COST ACTION TU0901.

1. C. SAMENVATTING

Context

Energiebesparing en thermische isolatie staan dezer dagen in de spotlight. Dit is inderdaad gerechtvaardigd en noodzakelijk om het hoofd te bieden aan de uitdagingen van de klimaatverandering en de toenemende energiekosten. Omdat thermische isolatie als een hoofdpunt behandeld wordt, worden de akoestische aspecten jammer genoeg dikwijls over het hoofd gezien en dit leidt tot belangrijke problemen: het isoleren omwille van privacyredenen of het isoleren om zich te beschermen tegen naburig of milieulawaai is een basisbehoefte en geen enkele bewoner/gebruiker van een gebouw keurt dat gebrek aan akoestisch comfort goed. Bouwelementen, het materiaal en het gebouw zelf zouden ontworpen moeten worden rekening houdend met de thermische EN akoestische overwegingen (en natuurlijk alle andere vereisten). Een geïntegreerde benadering is echter moeilijk omdat het knowhow in beide disciplines vereist.

Doelstellingen

Het algemene doel is een verandering teweegbrengen van het "monodimensioneel" thermische denken naar een geïntegreerde thermische EN akoestische benadering in bouw. Het project had volgende ambities:

- *Knowhow verkrijgen over een geïntegreerde benadering om zo te kunnen innoveren en geoptimaliseerde oplossingen te kunnen vinden;*

- *Softwaretools te ontwikkelen die de ontwerper zullen helpen om zowel akoestische als thermische overwegingen in een geoptimaliseerd ontwerp te integreren. Oorspronkelijk (subsidieaanvraag) was de doelstelling akoestische modules te creëren en om deze bij te voegen bij de DECYSYS EPR-software. Tijdens het project werd een ambitieuzere doelstelling bepaald: akoestische en thermische simulatiesoftware ontwikkelen dat bijgevoegd wordt aan de BIM basismodellers (REVIT, enz.). Het was de bedoeling om een soort thermische en akoestische BIM-“tool” te creëren, equivalent aan een “spelling checker“ van tekstverwerkingsprogramma's;*

- *Om databanken te ontwikkelen om zo de industrie te “forceren” om de prestaties van hun producten bekend te maken, ze te verbeteren en te innoveren (als gemakkelijke vergelijking met concurrerende producten). In een recentere fase, zullen links met de BIM modeller gemaakt worden;*

- *Om richtlijnen te produceren voor geoptimaliseerde thermische en akoestische oplossingen (en het toestaan voor innovatieve producten, de bouwelementen en gebouwen).*

Hoofdresultaten en besluiten

Drie hoofdthema’s werden ontwikkeld tijdens het project:

1) De “Bouwdetailatlas” met “robuuste” bouwdetails werd ontwikkeld:

De “Bouwdetailatlas” biedt robuuste oplossingen aan die voldoen aan de thermische en akoestische eisen. Ze vertalen de oorspronkelijk specialistische, technische eisen in meer begrijpbare eisen zoals oppervlaktemassa, afstanden, enz. Daarbij geeft de “Bouwdetailatlas” de vrijheidsgraden op om bepaalde details te wijzigen zonder noemenswaardige verliezen aan thermische of akoestische prestaties. Ook wordt gewezen op bepaalde aandachtspunten tijdens het ontwerp en de uitvoering en wordt uitgelegd hoe het systeem werkt. De “Bouwdetailatlas” bestaat voorlopig nog enkel op papier als een intern onderzoeksrapport dat aan BELSPO werd afgegeven als één van de projectresultaten. Een deel van deze informatie wordt echter gepubliceerd in verschillende artikels in het WTCB-tijdschrift. De volledige informatie wordt in de loop van 2011 echter ook gepubliceerd op de website van “Normen Antennes” van akoestiek alsook onder de vorm van een speciale WTCB Technische Voorlichtingsnota in een aanvulbare ringmap. Het idee is om deze TV-nota continu te blijven aanvullen met nieuwe geoptimaliseerde en geïntegreerde oplossingen en concepten die voldoen aan de thermische en akoestische vereisten. De verkregen onderzoeksinformatie wordt nu reeds continu verspreid via en gebruikt in conferenties en technische publicaties (ondermeer ook van derden) en vormt de basis voor oplossingen om te voldoen aan de NBN S01-400-1 “Akoestische criteria voor woningen” uit 2008.

2) Geïntegreerde akoestische en thermische voorspellingsmodules werden geprogrammeerd die functioneren binnen “Building Information Models” (BIM).

“Building Information Models” (BIM) bevatten niet enkel geometrische data (gevisualiseerd door een 3D-model), maar alle soorten van technische gegevens die gedurende het ontwerp proces en het bestaan van het gebouw toegevoegd kunnen worden. Aldus kan het bijdragen bevatten van alle bouwactoren (architecten, raadgevende ingenieurs, aannemers, speciale technieken,…). Een volledig software pakket werd tijdens het onderzoek ontwikkeld dat zowel de thermische als de akoestische prestaties kan voorspellen van de gevels van het BIM-gemodelleerde gebouw. Deze software kan daarbij communiceren met de Tiatab-database (ook ontwikkeld tijdens dit onderzoek) en kan aldus direct technische informatie van bouwelementen opnemen (zie volgend punt). Een hoofdbesluit van dit onderzoeksprogramma is dat werken en ontwerpen met BIM echt de toekomst is en dat dit een geïntegreerde technische aanpak toelaat. Deze evolutie is van uitzonderlijk strategisch belang voor de producenten van bouwelementen (bvb. in de wijze waarop de technische documentatie gecommuniceerd wordt). Door modellisatie via BIM is het mogelijk een volledig virtueel gebouw te “bouwen” én zijn toekomstige prestaties te evalueren. Natuurlijk laat dit veel beter een geïntegreerde aanpak toe waarbij veel problemen reeds van in het ontwerp vermeden worden.

3) Geïntegreerde databanken op het internet werden ontwikkeld. Deze kunnen rechtstreeks door de BIM-software geconsulteerd worden, waarbij een snelle data transfer mogelijk is.

Het kunnen beschikken over akoestische en thermische gegevens van bouwmaterialen en bouwelementen is echt noodzakelijk om een geïntegreerde aanpak van gebouwen toe te laten. Dit maakt het mogelijk om de globale prestatie van een gebouw te evalueren en om correct ontworpen bouwdetails toe te passen in het project. Nu is het nog een moeizame taak om deze informatie te bemachtigen: soms kunnen thermische gegevens op een website of in de technische documentatie van de fabrikant teruggevonden worden, maar veelal ontbreekt de akoestische data. En omgekeerd vindt men bij specifiek akoestische producten geen of nauwelijks informatie over andere technische gegevens zoals thermische isolatie, brandgedrag, enz. Veelal ligt de oorzaak bij het feit dat de andere technische gegevens gewoon niet gemeten werden. En dat betekent dan weer meestal dat de fabrikant niet gedacht heeft aan een technisch geïntegreerde aanpak met aandacht voor alle technische aspecten. Een web-gebaseerde databank werd ontwikkeld die communiceert met BIM-toepassingen en die technische gegevens bevat over zowel thermische eigenschappen, brandgedrag, akoestiek en andere karakteristieken. De toepassing omvat "zoekmachines" en kan door de producenten zelf ingevuld worden nadat deze een paswoord voor confidentiële toegang tot de databank heeft opgevraagd. De databank is beschikbaar op het internet op www.tiatab.be. Generische data (onafhankelijk van de bedrijven maar typisch voor een bepaald materiaal) werden berekend (gebruik makend van nieuwe voorspellingssoftware ontwikkeld tijdens dit onderzoeksproject) en opgeslagen in de databank. Het werk met de databank wordt voorgezet: de databank heeft internationale ambities (ook noodzakelijk: het is teveel werk voor de fabrikanten om enkel data in te vullen voor België) en wordt gepromoot gedurende het Europese COST-programma TU0901 dat pas van start gegaan is.

2. Terminology and key words for databases

BIM	Building Information Models
DECISYS	Name of a software company that produced the EPR software that has to be used by architects
$D_{n,e,w}$	Single rating in decibel expressing the acoustic performance of a small building element such as a ventilation slid. A higher value gives a better performance in "sound insulation". This value may not directly be compared to the value R_w used for normal building elements! Actually it represents the Rw-value of a wall of 10 m² in which the small building element is inserted, the wall itself having a sound insulation that is significantly higher than the small building element.
	Standardized level difference, in decibels, between two rooms corresponding to a reference reverberation time of 0.5 s in the receiving room
$D_{nT,w}$	Calculated single rating value in decibel from a spectrum of standardized level differences D_{nT} as to the procedures of EN ISO 717-1
$D_{Atr} = D_{ls,2m,nT,w} + C_{tr}$	Characterisation of the sound insulation of a façade pane in decibel. It is the A-weighted standardized sound pressure level distance between a measurement point at two metres from the façade pane and the noise level inside the room and corrected to a reverberation time=0.5s. Requirements about the façade sound insulation are expressed by this rating in NBN S01-400-1
Enhanced acoustic comfort	Quality level as is defined by the Belgian standard NBN 400-1:2000 ("Acoustic criteria for dwellings"). This quality level is considered by approx. 90% of inhabitants as acceptable for normal neighbour or environmental noise
EPBD	European Energy Performance of Buildings Directive
EPR	Energy Performance Requirements
IFC	Industrial Foundation Classes (ISO standard for exchanging building information)
$L_{Ainstal,nT}$	The A-weighted standardized equipment noise in decibel as defined in NBN S01-400-1:2008 "Acoustic criteria for dwellings" and derived from three non-simultaneous measurements, each over the complete working cycle and corresponding to the measurement conditions as described in EN ISO 10052:2005
L_{nT}	Standardized impact sound pressure level in decibel: This is the corrected level of pressure in a receiving room for a certain frequency band, when the standardized tapping machine is functioning on the floor in the sending room. The correction recalculates the sound pressure level to the value one would obtain if the reverberation time in the receiving room would be 0.5 s
$L_{nT,w}$	Calculated single rating value in decibel from a spectrum of standardized impact sound pressure levels L_{nT} as to the procedures of EN ISO 717-2. It characterizes the impact sound insulation: a higher value indicates a worse situation!
ΔL_w	Single rating (EN ISO 717-2) in decibel expressing the improvement in decibel due to a floating floor of the impact sound pressure level in the

	receiving room, generated by the standardized impact tapping maching on the floor in the sending room (difference situation with and without floating floor). A higher value expresses that the floating floor reduces better the impact sound giving more acoustic comfort
Low Energy Building	Buildings with the explicit intension of using less energy standard buildings. However, on the contrary to the label “Passive House” no specific requirements are defined
Normal acoustic comfort	Quality level as is defined by the Belgian standard NBN 400-1:2000 ("Acoustic criteria for dwellings”). This quality level is considered by approx. 70% of inhabitants as acceptable for normal neighbour or environmental noise
Passive House	According to the definition provided by the consortium Promotion of European Passive Houses, the following requirements have to be fulfilled: (1) a maximum en-energy space heating demand of 15 kWh/m²a, (2) a primary energy demand for all end-uses including electricity for appliances is not higher than 120 kWh/m²a. Note: m² refers to the net heated floor area
R	Sound reduction index expressed in decibel: Ten times the logarithm of the ratio of the incident power on and the transmitted power through a building element. This is normally measured according to the procedures of EN ISO 140-3 in an acoustic laboratory. A higher value indicates a better resistance against the passage of sound through a building element
REVIT	Building Information Modeller of the Autocad company
R_w (Weighted Sound reduction index)	Calculated single rating value from a spectrum of sound reduction indices R as to the procedures of EN ISO 717-1
STEP	Standards ISO 10303, series of standards describing formats of data for BIM
T	Reverberation time expressed in seconds. This is the necessary time for a frequency band so that the sound pressure level drops with 60 dB after the sound source is cut. When the reverberation time in a space is long, this results in more noise in this space as earlier emitted sound can cumulate with recently emitted sound to higher levels. Typical dwelling spaces have an average reverberation time of 0.5 s. This is why all standardized values recalculate the sound pressure level in the receiving room as to the level it would have in the same space but with a reverberation time equal to 0.5 s
WHO	World Health Organization

Key words for databases	BIM / Building Information Model / TIATAB database / Thermal insulation / Acoustic insulation / Acoustic comfort / Robust details / Façade sound insulation / Ventilation / Prediction Programs / EPBD / Prediction of the façade insulation/ Prediction of the sound insulation of monolithic walls / Prediction of the sound insulation of double walls / Integrated acoustic and thermal approach / Sound insulation of terraced houses / Sound insulation of apartments / Fire performances / Acoustic structural building concepts / Elastic interlayers / IFC

3. Introduction

3. A. CONTEXT

We are entering an era in which the demand for energy exceeds the offer, fossil energy reserves are diminishing, energy prices are always on the rise and the feared climate change implicates the necessity to reduce CO_2-emissions and as such fossil energy consumption. There has so much been said about this topic, that most building professionals are convinced that they need to focus on aspects allowing the reduction of energy consumption. Moreover, more severe thermal requirements are imposed in most countries to cope with these challenges. From 2007 onwards, Energy Performance Requirements Laws (EPR), imposing an obligatory examination of the energy performance of buildings in the project phase, became a fact in our Regions. Ultimately, this lead to numerous innovations, low energy buildings and even passive houses requiring almost no heating anymore.

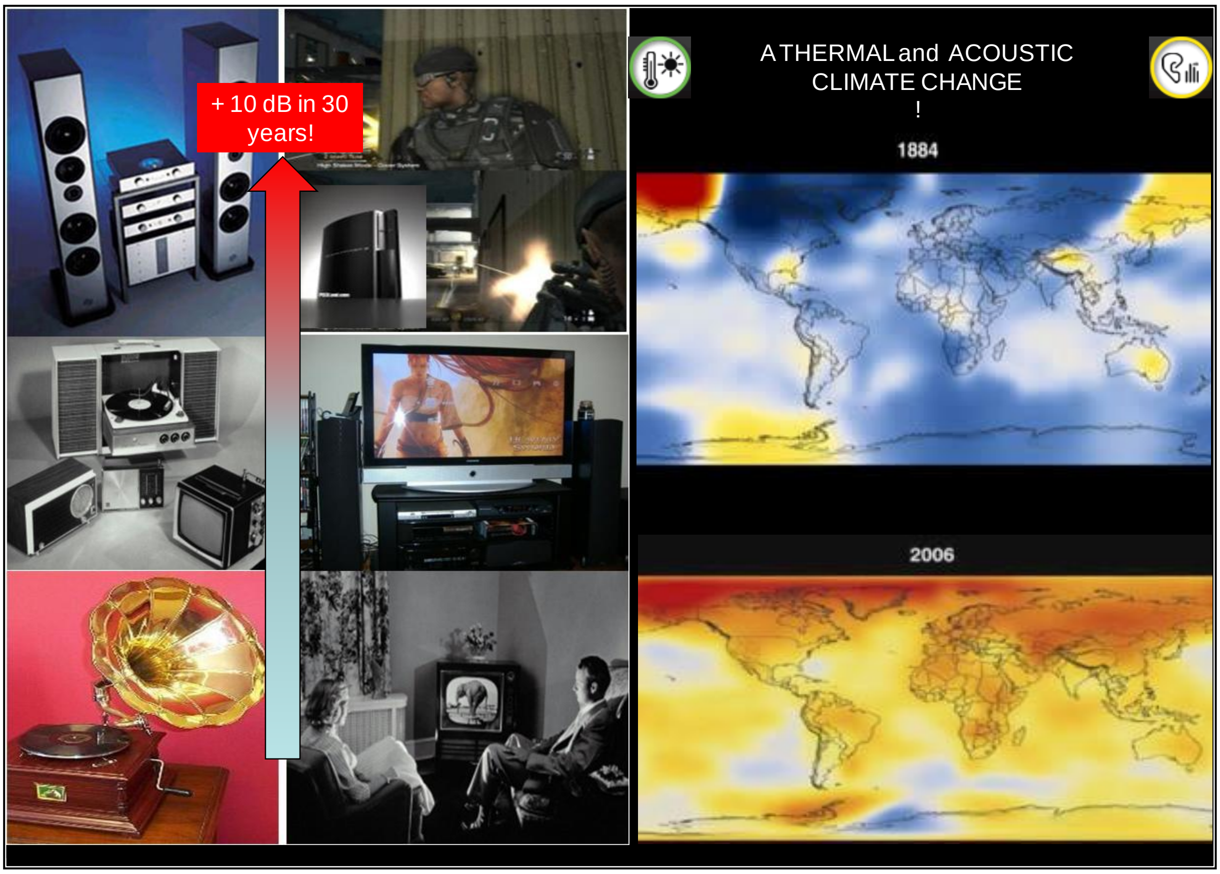


Figure 1: There is not only a well-known fear of thermal climate change, the indoor and outdoor environment is characterized by an ever increasing noisier climate. Average noise levels at the neighbours have increased up to 10 dB. Better sound insulation is necessary as a protection for health and comfort reasons.

Unfortunately, the focus on thermal aspects very often goes together with a lack of attention to the acoustic aspects in construction. How often have we seen buildings being renovated, first with the option to get a better thermal insulation and a couple of months later, being forced by dissatisfied occupiers, the work needs to be redone for acoustical reasons (creating perhaps again a worsening of the thermal insulation). In many buildings, problems arise due to a lack of ventilation. When the situation is examined, experts note that there is a ventilation system installed, but that it is closed off by the inhabitants because it allows too much traffic noise to come through or – if it is a mechanical device - because it is making too much noise. An integrated approach with respect to thermal AND façade sound insulation might avoid a lot of damage, dissatisfied customers and costs! As the thermal renovation of buildings is regionally subsidized, it is also a matter of good governance to take in account both aspects to avoid the waste of public funds.

Even manufacturers of building materials and systems very often create innovations that are thermally optimized, but when applied in construction behave acoustically bad.

There is not only a thermal climate change, noise has been increasing in the indoor and outdoor environment (Figure 1). So we should also build houses with a better acoustic protection and even anticipate a further worsening of the "acoustic climate". To cope with this changing acoustic climate, this requires the same attitude by building industry as exists now towards the aspects of thermal insulation. This is even more so as it is health threatening.

The change in "acoustic climate" is evident for the outdoor environment: car, train and air traffic is ever on the rise. Belgium has a very dense population, it is characterized by a very important urban sprawl implicating mass traffic between dwellings and the working place. Urbanism is more orientated on architectural aspects and the maintenance of open spaces: no or only little attention has been paid to the acoustic consequences of the implantation of dwellings even near major roads. A different policy in the Netherlands - though also a similarly dense country - allowed to avoid a lot of acoustic problems. The law "Geluidhinder" even obliges authorities to take measures if the outdoor noise near dwellings becomes too important. So actions tackle especially the noise source (road infrastructure, speed limits, traffic deviation,…) making façade sound insulation, although still necessary sometimes, at least far less critical than in Belgium.

	Provincie Vlaams-Brabant			Vlaanderen	België
Buurtproblemen - 2006	helemaal wel	eerder wel	totaal	totaal	totaal
onaangepaste snelheid in het verkeer	19,46	35,70	55,16	54,39	60,61
inbraak in woningen of andere gebouwen	20,70	30,38	51,08	46,59	54,92
agressief verkeersgedrag	16,66	25,84	42,50	39,86	54,11
rommel op straat	10,78	23,76	34,54	36,32	41,85
diefstal uit auto's	16,94	16,70	33,64	30,46	38,99
geluidsoverlast door verkeer	12,08	21,56	33,64	26,66	34,94
fietsendiefstal	12,76	15,35	28,11	30,16	31,02
diefstal van auto's	10,21	16,03	26,24	22,97	29,53
andere vormen van geluidsoverlast	6,75	14,96	21,71	20,17	26,06
vernieling telefooncellen, bus- of tramhokjes	7,99	11,24	19,23	18,00	27,24
aanrijdingen	6,86	11,43	18,29	19,22	23,74
bedreiging	7,78	7,84	15,62	14,58	19,24
overlast van groepen jongeren	3,47	11,84	15,31	17,92	26,30
bekladde muren of gebouwen	5,38	9,73	15,11	14,00	21,47
geweld	8,64	5,75	14,39	16,32	23,30
overlast verbonden aan druggebruik	6,93	7,23	14,16	17,62	23,90
mensen worden op straat lastiggevallen	7,94	5,87	13,81	14,32	18,91

+

=61 %

Table 1: "Veiligheid door een andere bril bekeken" conference by Mr Lodewijk De Witte, Governor of the Province of Flemish Brabant, 2nd of October 2007; Slide illustrating the speech on neighbourhood problems as experienced by citizens

Unfortunately, as in Belgium, all focus is on the thermal insulation - and less or none on façade sound insulation - this is ever more creating serious problems.

The results of an enquiry in Belgium, Flanders and the province of Flemish Brabant about the dissatisfaction of people with their living environment are given in Table 1. People were asked if they were “very dissatisfied” (second column) or “rather dissatisfied“ (third column) with different aspects of their environment. Many different themes were proposed in the enquiry varying from the type of traffic, problems with theft and vandalism, drugs, graffiti, junk on the streets, the feeling of insecurity due to young gangs wandering in the street, etc. Two themes had to do with noise in the outdoor environment: one deals with specific traffic noise, the other with “other type of noise nuisances”. Both themes together indicate that up to 61% of the population is bothered by too much noise in their outdoor environment! This rating scores the highest of all themes of dissatisfaction…

There is also more “noise at the neighbours”. Generally, one can estimate that the noise “at the neighbours” has risen with almost 10 dB in the last 30 years with the aggravating fact that it is especially low frequency noise that is ever increasing. The technical evolution in appliances for hifi, tv, home theater systems and games in combination with a reduced cost is largely responsible for this. Low frequency signals can be quite accurately emitted with these appliances and this opens the market for music, games and movies that make use of these new low frequency emitting possibilities to add a dimension of sensation reality in their applications. Multimedia applications with virtual reality entertainment are on the move and will probably continue to do so in the next decades. New dwellings will be mostly used for at least 50 years and sustainable constructions should cope with these noise evolutions and should offer sufficient protection. Last but not least: the percentage of single family houses (with few sound insulation requirements) is decreasing rapidly compared to the number of terraced houses and apartments (with high sound insulation requirements) due to the lack of available building lots.

Too often acoustics is associated with comfort, insinuating that a lack of sound insulation has no more influence than that. On the contrary, many studies have shown that too much noise generates serious effects on the health of people.

Relevant information can be found in the document published by the WHO in 1999 (http://www.who.int/docstore/peh/noise/guidelines2.html) and in the documents made available by the Working Group on Health and Socio-Economic Aspects on the site http://ec.europa.eu/environment/noise/health_effects.htm (an EU network of acoustic experts). Interesting to know is that it can be shown that even people who pretend to be used to the noise and who claim not to be effected by it, actually are unconsciously as effected in their health by this noise (especially during the sleeping periods) as people who protest against the noise.

In January 2008, a new acoustic standard was published: *NBN S01-400-1: Acoustic criteria for dwellings* replacing the standard NBN S01-400 from 1977 and NBN S01-401 from 1987. The criteria in the document take in account this noise evolution and go beyond the old requirements. This demands much more technical knowledge of the building professional.

In the older requirements, it was rather simple. Let us demonstrate this for the airborne sound insulation between dwellings: if a certain “category” (level of sound insulation) was required, it was sufficient to have common walls which tested the same “category” in the laboratory. The requirements to obtain the same category in laboratory were some 5 dB higher than what was required in situ, this to account for the effect of volume, surface and flanking transmission in situ. For the old lower requirements, this basic approach was for many cases valid as the flanking transmission for most traditional constructions remains limited for requirements up to 52 dB.

For airborne sound insulation, the new standard requires 54 dB for the category of “normal acoustic comfort”, compared to 48 dB in the old standard; for the enhanced acoustic comfort, this is similar but 4 dB higher in both standards. So in the new situation, the approach towards the flanking transmission cannot be brought in account so easily and can certainly not be approached by the old 5 dB difference rule. So with the new acoustic standard, the building professional urgently needs to become an acoustic expert. Because of the thermal requirements, he also needs to become a thermal expert, etc. Of course he can call in experts, but as this not a tradition for smaller projects, this would mean significant extra building costs.

The alternative approach is to follow building rules and robust building details.

There is not much sense in just giving acoustic building rules, fulfilling acoustic requirements, but leading to non-conformities with thermal requirements and vice-versa. The same is valid for new building elements and products: e.g. some manufacturers have been developing ventilation slids without acoustic attenuation. Of course, this cannot be applied because of insufficient sound insulation to comply with NBN S 01-400-1. The integration of both disciplines in the design of new building elements or in the design of a construction is a pretty complicated matter for the building professional. It definitely is also the case for the expert. Though this sounds strange, one should understand that the expert is most of the time only an expert in his own technical field: most experts in energy building physics have only superficial acoustic notions and of course, the other way round for the acoustic expert.

So the idea was borne to start a research project that tries to unite experts of both disciplines, make them become more familiar with the other’s discipline and to come to solutions for the building professional and manufacturer that stimulates the integrated conception with respect to both acoustics and thermal aspects.

3. B. RESEARCH GOALS

In this project the principal objectives and research topics/goals were:

- *To get know-how about an integrated approach so as to be able to innovate and find optimized solutions;*
- *To constitute a working group of mixed acousticians and non-acoustic building physicists with good knowledge of each others discipline (far beyond the passive general knowledge), able to form the nucleus for a new integrated approach in standardisation, legislation, the development of guidelines and the development of innovative products, building elements and construction;*
- *To realize software tools that will help the designer to integrate both acoustic and thermal considerations into an optimized design. Originally (subsidy request) the objective was to create acoustic modules and to attach them to the DECISYS EPR-software. Now, a more ambitious goal was set to create acoustic and thermal simulation software that can be inserted/attached to basic BIM modelers now already being used by some architects and already being taught at universities. The objective*

is to advance as far as possible with the idea of the thermal and acoustic BIM equivalent of a "spelling checker" of text treatment programs;

- *To create databases and as such force the industry to declare the performances of their products and to improve and innovate them (as an easy comparison with competing products will certainly require). In a later phase, the objective is to examine the possibility of an IFC-format based database;*
- *To generate guidelines for optimized thermal and acoustic solutions (and allowing as such for innovative products, building elements and buildings);*
- *To collect the know-how for the future acoustic and thermal standards (> 10 years, beyond EPR and NBN S01-400);*
- *To generate in the long term (>5 years) the draft of a standard, describing a quality label that takes into account the thermal and acoustic performances;*
- *To help renovation subsidizing authorities to double the effect of their effort: get for the same money thermal AND acoustical good renovations. We could help to realize this by good prescriptions in the requirements with the above mentioned guidelines and to assist them in future actions;*
- *Report to several European standardization committees and research groups about this new approach.*

3. C. STRATEGY

At the start of the project, a mixed group of experts was constituted as well as an accompanying steering committee. There were more acousticians in this mixed group of experts (the research project was introduced by acousticians), so first a couple of courses on thermal insulation, ventilation and EPB were organized.

Three main axes were chosen to develop during the research project:

The creation of an Atlas of integrated building details

The thermal requirements also offer interesting opportunities for acoustic building solutions. For instance, with the new thermal requirements, it is impossible to get sufficient thermal insulation using "thermal blocks" only. So the consequence is that typical thermal insulation such as mineral wool, PU, etc. needs to be used in the common walls between apartments. Of course, these materials cannot be exposed as such and need to be hidden by a lining or to be put in the cavity between two walls. This is an extraordinary opportunity to generate acoustic improved concepts making use of mass-spring-mass functioning common walls and/or to introduce linings that diminish flanking transmission. This was the starting point on the creation of the Atlas of integrated Building Details.

The Atlas of Integrated Building Details offers robust solutions that comply with thermal and acoustic requirements and translate the original requirements in more "understandable requirements" such as surface mass, distances, etc. The Atlas explains equally the degrees of liberty one has to modify the presented details without losing acoustic or thermal performances, specifies attention points in the project and execution phase and explains how everything acoustically works.

DELIVERABLES: The Atlas of Building Details, started up in TIATAB, exists on paper yet only as an internal research document that is given to BELSPO as one of the research deliverables. Due to the size limitation of this report, we are only able to give some extracts (consider these as “teasers”) here. Part of the information will be published in several articles by BBRI. The complete information will also be published on the “Normen Antennes” website (expected autumn 2010) and under the form of a special Technical Note of the BBRI that will be edited under the form of ring binders. The idea is *to continue to complete* these robust details with any new integrated solutions or concepts that comply with the thermal and acoustic requirements. The obtained research information is now being continuously used in all conferences, technical publications by third parties and forms a basis of responses to comply with the new requirements of NBN S 01-400-1:2008 “Criteria for acoustic comfort in dwellings”.

The creation of integrated acoustical and thermal prediction software tools that can function in a BIM environment

One of the objectives of TIATAB was to develop application software to perform both thermal and acoustic simulations using the same geometrical data set. In the subsidy request, this was supposed to be an acoustical software that would be attached to the existing EPR software DECISYS that is used in the Flemish Region to calculate the energetic performance of buildings. We quit the idea of working with the DECYSIS EPR software in favour of the very promising research with Building Information Models. BIM contains all the geometrical information needed to make thermal and acoustic simulations and offers far better and extensive opportunities than the proposed work in the subsidy request. It is the way of the future (“the next big step in construction” as was mentioned in a symposium) and is seen by the Directorate of Research and Innovation as a strategically important new field. This change in approach was defended and approved in the first meeting of the steering group. Already at the start of the project, we got into contact with UGent were a preliminary internal research project within UGent was started about Building Information Models. We very quickly decided on collaboration on a win-win basis that was ever more extended during the project (also partially due to the departure of a key researcher of BBRI).

The principle of Building Information Models (BIM) is that it does not only contain geometrical data (visualised by a 3D-model), but all kind of technical data that can be added throughout the design process and life of the building. It can contain attributions of all interveners in its design (architects, consulting engineers, contractors,…). The global idea is to extract most of the suitable data from the BIM and use it to make acoustic and thermal prediction calculations of the performance of the building. As such this could in its utopian version work as the acoustic and thermal equivalent of the spelling check tools in text programs, helping designers to optimize thermal and acoustic characteristics of buildings.

The more global introduction of BIM in the Belgian building industry would of course have major consequences: producers of building elements would have to deliver technical information in a specific digital way, authorities could control in a quick way if required performances are met in the design phase etc. This is not really something of the future: in some Nordic countries, it is necessary to introduce a BIM for public buildings if one wants to obtain a building permit. So this is absolutely of primal strategic importance for the global building industry and for BBRI as a competence centre for building technology. BIM knowledge generated by TIATAB is now being exploited by a BIM cell within BBRI and VIBO.

DELIVERABLES: A fully workable program was developed that can predict thermal performances and the façade sound insulation of buildings. This program can communicate with the TIATAB database and extract directly technical information (see next point). To the subsidizing authorities of BELSPO, a complete version of the program was given. A BIM cell was created within BBRI. Partners got acquainted with this way of working of the future. UGent is examining how to start exploiting the program in web based consultations. In this report, we were able to write in a summarized text some information about how this program was developed and how it works.

The realization of databases on the internet

The availability of acoustic and thermal data of building elements is a necessity in this integrated approach. This information is necessary to estimate the overall performance and to be able to apply correct building details in the project. Nowadays it is a difficult task to obtain this information: sometimes one can find data about the thermal performances on the website or technical documentation of the producer, but then very often the acoustic information is missing. And vice versa: for building elements with specific acoustic applications, the thermal information will sometimes be missing. Very often the data is missing because it simply hasn't been measured. And that's very often an indication that the manufacturer has not been thinking about this integrated approach.

The research group thought about a strategy that would stimulate manufacturers to test their products at least for both aspects, to make this information easily available for consultants and contractors and to store it in databases that can be read by BIM applications.

The idea was to create a web database with product characteristics. Strategic points of departure were:

a) *It is the manufacturer who enters the data himself.*

   The database makes it clear that the manufacturer is the sole responsible for the presented data. There is no official control by BBRI for the entered data, though we reserve the right to eliminate data. So the available information has about the same status of "correctness" as what can be typically found on manufacturer's websites or in technical documentation. There are some minor control tools in the database such as an automatic recalculation of the different acoustic single ratings and comparison with the manually entered single ratings. This tool allows detecting wrongly entered spectral information. The database allows the uploading of test reports so it is up to the manufacturer to convince the user of the correctness of his data. This is also a "Darwinian" approach: as it is easy to compare similar products, wrongly entered data for a product can/will be detectable and will as such eliminate itself as a possible choice. There are many reasons for this strategic approach: the main advantage is that the site can expand itself more rapidly as there is a multitude of manufacturers entering the data and not just one person in BBRI, the continuation of the database after this project is assured, entering the data ourselves is a huge and ungrateful task, there is the risk of entering errors ourselves and liability risks, it could be difficult to obtain correct information, as it is so much work, there is the problem of data that would be not valid anymore or data about products that are no more existing (now this remains the responsibility of the manufacturer himself), etc.

b) *Not only acoustic and thermal data can be entered and it is easy to introduce new data technical fields*

Manufacturers might have products with acoustic and thermal performances that comply with requirements, but perform less well than competitors. Publishing this information next to the better performances of competitors might not be such a good marketing idea and so it will not be done. To avoid this, the possibility to enter multiple technical characteristics might be a solution because the product might have a higher technical score for some other technical performance (e.g. fire resistance,…) which would yet stimulate the manufacturer to enter the data…

c) *Easy communication with the BIM prediction software developed in TIATAB is a must*

The problem especially with acoustic prediction software is the lack of available data. If these are not available, one has to enter spectral information manually which is a tough job because of the quantity of figures one has to enter per product. There is also the risk with such quantities of entries that something is wrongly encoded. All of this is not stimulating to make a prediction.

So the TIATAB database needed to communicate easily with the Building Information Model.

d) *Nomination of products must be the same as in the BBRI TECHCOM database of the BBRI*

This should allow a future combination of both databases.

e) *The main language of the database is English*

The reason for this strategic choice has to do with the small market that Belgium represents for multi-nationals. It is a laborious job to enter all of this data. But when the language is in English, it can be used all over Europe and then the market is big enough to motivate this type of work. The database allows for descriptions in many languages, so it is left to the manufacturer how much effort he wants to put in local markets.

f) *The database will be presented to European research organizations e.g. those that work together in COST projects*

This has been done and is now an official work item (stimulation of local industry to publish test results on the database) of COST Action TU0901 "Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions".

Maximum security procedures need to guarantee that only manufacturer can access his part of the database with his products.

g) *Manufacturers independent acoustic information was calculated and stored in the TIATAB database*

The goal of this work is double. First of all, calculated data give good information about acoustic performances of walls and floors that cannot be easily found and makes the database already as such most interesting for the building professional. Secondly, it offers neutral information of what can be obtained by some building element; As such, it is an interesting comparison with the commercially available products that are stored in the database.

DELIVERABLES: This program is available on the internet as www.tiatab.be. A copy of the software has been given to the subsidizing authorities of BELSPO. In this document a summary of how it works is given in a text by its main developer. Two chapters are also given which describe how the product neutral information was calculated and why this is not always possible to do so (as such again motivating the necessity of laboratory measurements and the need for a database as developed here).

3. D. HOW TO READ THIS DOCUMENT

This document is composed of a number of independent chapters (so they can be read separately) that tries to give an overview of the delivered work; More detailed information can be obtained by the research partners and/or will be published in more extensive reports, articles and websites or are now being used in most conferences that are given by the people who have been participating in this work.

The document contains chapters that can be subdivided in different “families” belonging to the major strategic goals of the TIATAB research.

a) For the building professional, more easily accessible information about integrated building solutions, details and explanation about how it all works, can be found in the following extensive chapters:
   - *CHAPTER 6: Acoustic and thermal structural concepts for terraced housing and apartments with decoupled double party cavity walls*
   - *CHAPTER 7: The problem of combining high façade sound insulation and the need for ventilation*

b) Information about the strategic “Building Information Models” approach and the creation of the TIATAB database and its generic values can be found in:
   - *CHAPTER 4: Towards an integrated approach using integrated acoustic and thermal databases and prediction tools attached to Building Information Models*
   - *CHAPTER 5: Determination of default values for the sound insulation indices of monolithic construction elements and double walls*

4. Towards an integrated approach using integrated acoustic and thermal databases and prediction tools attached to Building Information Models

4. A. INTRODUCTION

The original project proposal described three objectives related to information technology: the elaboration of a product database providing acoustic and thermal material properties, the implementation of the newly developed acoustic standard [Ref. 4.1] in a software module and the automatic exchange of geometric building information between the latter module and the existing Flemish energy calculation software: the EPR application [Ref. 4.2]. At the moment the SmartLab research team started its activities, the elaboration of the product database was initiated by the BBRI, meaning that the most important design issues were already encompassed. Although a serious amount of time was invested in reviewing the design options and transferring the existing code from one implementation platform to another (from Ruby to .Net), this task will not be further described here since the nature of the work was mostly operational. In contrast the implementation of the new acoustic standard and, even more important, conceiving methods for an automatic information exchange concerning building geometry is the main focus for the SmartLab team.

At the time the TIATAB project proposal was elaborated, the initial idea was to extract geometric information from the EPR application since there does exist an overlap in the data required. More precisely, one planned to programmatically screen the PDF output forms from the EPR application for useful data. In parallel, the SmartLab team was working on methods to automatically extract geometrical data from digital building models to feed this data to the EPR calculation software. Evidently this work was very useful for the TIATAB project, enabling a direct link between a digital building model and an acoustical evaluation module, without using the EPR application as a step between. Moreover, the EPR calculation module itself had been a target module for the SmartLab team, inquiring exchange methods between digital building models and calculation modules for the last two years. These efforts resulted in a software prototype: the UGent-Epw application, enabling an automated data transfer between a digital building model and an EPR calculation module, albeit that the methods used were exclusively useful for orthogonal geometry [Ref. 4.3]. Certainly a more generic approach is, at least, desirable.

4. B. PROBLEM STATEMENT

The main research topic is summarized as follows: how can we automatically exchange the data required between digital building models and thermal, acoustic evaluation tools, rendering the design process more efficient? At first we need to define the concept of "a digital building model". Recently the application of the Building Information Modeling (BIM) paradigm seems to gain importance in design offices all over the world. This new paradigm stands for a huge shift in the way designers construct digital building models, and the most important difference in comparison to conventional modeling techniques is the semantic richness embedded in BIM models.

In contrast to merely describing geometrical objects (lines, arcs, boxes,...) as in conventional modeling practices, the BIM paradigm introduces the concept of object-oriented modeling, meaning that the building model is composed by objects resembling real world things (door, roof, wall,...). Geometrical descriptions can only exist as a representation of a certain object or building component. Moreover, one has the ability to add all kinds of attributes to the components, e.g. the materials a wall is constituted by.

Secondly the idea of parametrically defining component geometry was introduced. As stated before a component is defined by several attributes, which might have a geometrical nature. These kinds of parameters describe the component's shape, possibly in relation to another component, e.g. the position of a door within a wall.

Another feature of present BIM applications is the availability of more abstract objects as rooms, zones or spaces. It should be mentioned that, although the range of applications for those concepts is huge, the present implementations are still young and still have many problems to be resolved. However, the space-object is of outmost importance for our purpose, since thermal and acoustic evaluations both use this concept as the primal starting point for the respective calculations: acoustic performance is measured between rooms or between a room and the environment, as is the case in this research project, since we want to evaluate the acoustical insulation of a building façade. Likewise the energetic or thermal performances also relate to rooms, spaces or zones. In addition, space-objects can be defined in relation with its bounding constructions, meaning that the space-objects have references to components (walls, floors, roofs, windows) delimiting the space or room. These references also provide the geometrical representation for the boundaries.

Considering the facts abovementioned, the BIM paradigm should be able to, theoretically at least, provide digital building models which contain a lot of reusable data for our purpose. Now, what are the possibilities to extract this kind of data from a digital model? For this purpose two strategies exist: one could use a the application programmers interface (API) of the host modeller, which is a proprietary set of objects and methods or one could use the ISO standard for exchanging building information, namely Industry Foundation Classes (IFC) developed and maintained by the BuildingSmart Alliance [Ref. 4.4]. Surely the former is most likely to be more efficient since the internal data structure of the model is exposed. On the other hand, this strategy is exclusively applicable for a particular application and demands for as many exchange modules to be developed as the number of proprietary models one wants to use or serve. This consideration leads us to the conclusion of developing one single module to extract the data required based on a IFC model, the building data is then fed into thermal and acoustic evaluation modules.

4. C. OBJECTIVES

Before describing the research objectives more detailed, the data required for energetic and acoustical evaluations is listed. We will focus on the geometrical part of the data transfer, since the geometrical difficulties and respective solutions make up the difference in respect with existing procedures. The ability to store and retrieve physical material properties is of course very important and was implemented in the database task mentioned before. As summarized in Table 2, the required geometrical data consists of the internal and external volume V (m^3) per space i.e. as seen from the in- and outside, the internal and external area A (m^2) for each bounding construction as well as its surface normal N (providing the orientation and inclination angle i.e. Θ and Φ).

Next, we evaluate the data structure of the IFC2x3 model scheme [Ref. 4.5] with respect to the required data previously described. In fact, from a geometric point of view, the IFC model scheme defines the building in two ways. The most straightforward description is the one which individually defines each component accompanied by its own geometrical representation. This representation consists of a two dimensional plan representation as well as a three dimensional solid representation e.g. in most cases a wall is defined by an extrusion of a two-dimensional profile, residing on a certain storey level. Note that spaces also have a three-dimensional representation, albeit not always as accurate as one might expect (in Revit Architecture for example more complex spaces are defined by a bounding box). Thus, the three-dimensional representation for the building as a whole is formed by the collection of the individual building components, with very little, if any, topological relations. In practice this way of describing a building's geometry is most likely to be well supported by commercial BIM applications.

		V,zone (m^3)	A,construction (m^2)	d,construction (m)	Θ,construction (°)	Φ,construction (°)
Energy	Qt,zone,m (MJ)		■	■		
Energy	Qv,zone,m (MJ)	■	■			
Energy	Qi,zone,m (MJ)	■				
Energy	Qs,zone,m (MJ)		■		■	■
Energy	ηutil,zone,m (-)	■	■	■	■	■
Acoustic	Ratr (dB)	■	■			
Acoustic	La (dB)				■	■

Table 2: Geometric data required for the energy and acoustic standard [Ref. 4.1 and Ref. 4.2]

In contrast the second strategy has found until today less attention but is much more interesting from a topological point of view. This strategy starts from the idea of describing a building based on the spaces enclosed by its structure. In addition, each space description holds pointers to the construction components by which it is bounded and, more interesting, to a geometric object representing the shape for that specific boundary. By generating the geometric representations for each individual boundary and collecting them for all boundaries one is able to reconstitute the inner dimensions of a space instance. The geometric descriptions for the individual boundaries will most likely be a planar curve. Triangulating these curves enables us to calculate the space inner volume and inner area quantities for the bounding constructions. A next step consists of generating the space external volume and external construction areas, based on the information previously processed in combination with data describing the thickness for each bounding construction. A very important step at this point is the processing of a directed, triangulated closed mesh as the geometric representation for the space inner dimensions. Note that in the previous step we already triangulated the curves representing the inner boundaries; however, this step did not necessarily result in a directed, closed mesh representing the spaces. Indeed, some triangles constituting the mesh might not have their neighbourhood defined correctly. Therefore an intersection test for all triangles has to be performed, after which a straightforward offset algorithm for each mesh vertex is executed, resulting in the external dimensions of the space. Summarizing the abovementioned leads to the following objectives:

For each space:

- *collect all spaceboundaries and generate the corresponding geometrical representations as described by the model;*
- *for each spaceboundary: triangulate the original curve provided by the geometrical representation and reference each triangle to the construction component;*
- *search for intersections between all triangles and retriangulate if necessary, add all triangles to the mesh data structure and check all triangles for neighbourhood, this results in a mesh representing the inner dimensions of the space;*
- *for each triangle in the mesh data structure: direct the surface normal outwards and generate a solid object based on the construction component thickness, providing the outside dimensions for the boundary, thus for the space mesh as a whole;*
- *at this point all geometrical data is generated and the required information for the energetic and acoustical evaluation can be delivered in.*

4. D. METHODS

In collaboration with the Department of Electronics and Information Systems a IFC-Parser application was developed, enabling the mapping of an IFC file on Java and .Net class instances. Combining the IFC2x3 model scheme and the functional requirements needed for the evaluation methods, the set of *IfcRelSpaceBoundary* instances for each *IfcSpace* delivers the best entry point. Each of these *IfcRelSpaceBoundary* instances incorporates the four following properties (Figure 2):

- *RelatingSpace: references to one space that is delimited by this boundary;*
- *RelatedBuildingElement: describes the construction element used as a boundary for the space (assuming that such a physical boundary exists);*
- *ConnectionGeometry: establishes the geometrical relationship between an IfcSpace entity and the related bounding construction;*
- *InternalOrExternalBoundary: states whether the bounding construction neighbours the exterior or the interior;*
- *PhysicalOrVirtualBoundary: states whether the space is bounded by a physical boundary or by a virtual (open) boundary.*

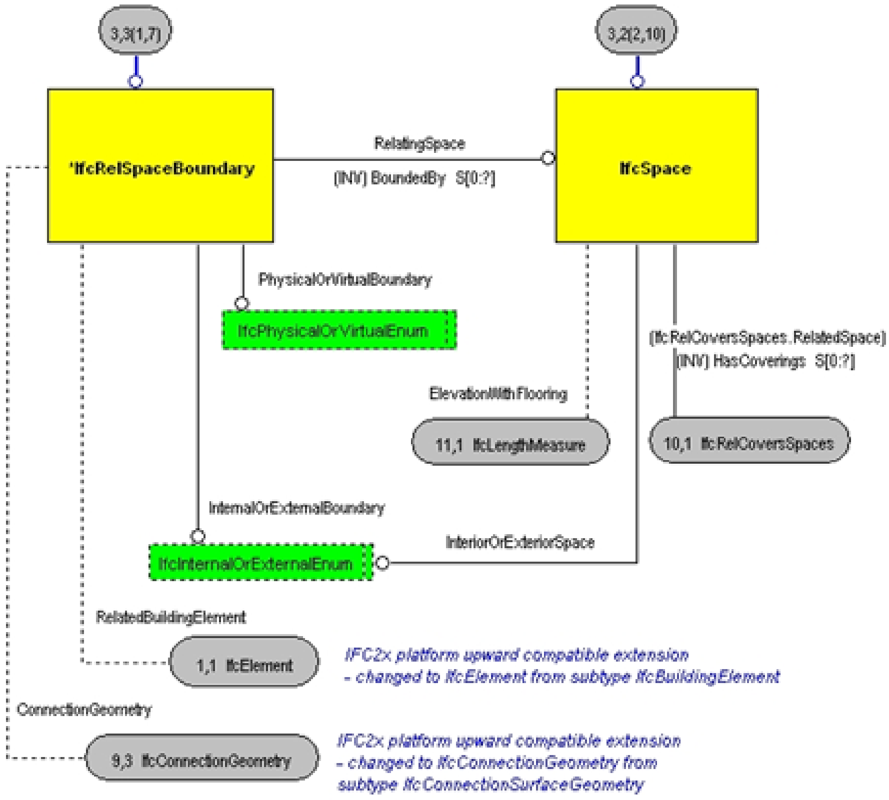


Figure 2: The EXPRESS definition of the IfcSpace in relation to the IfcRelSpaceBoundary entity

The argument for using the *IfcRelSpaceBoundary* instances as a starting point has a geometrical and relational nature. The IFC2x3 model scheme provides for several ways to geometrically represent an *IfcSpace*, varying from roughly described bounding box definitions to accurately defined B-Rep solid definitions. Evidently, since we want for the evaluations to be as precise as possible, an exactly defined shape for the *IfcSpace* instances is required. Moreover, each geometrical part of an *IfcSpace* geometrical representation has to be related to an *IfcBuildingElement*, since the physical properties of the construction used for this particular *IfcBuildingElement* are required for the evaluations.

Previous considerations, i.e. the need for an exact geometrical representation of spaces related to the constituting construction components, renders the availability of the shape by the individual *IfcSpace* geometrical representation useless since there are no relations provided with the *IfcBuildingElements* which bound it. The only way to process the exact shape with relating components is by using the set of *IfcRelSpaceBoundary* instances which each hold a pointer to the *IfcElement* bounding the space. *IfcRelSpaceBoundary* instances have an optional property called *IfcConnectionGeometry* which provides for a geometrical description of the surface connecting a construction component to a space. It is by assembling these connecting surfaces that we are able to develop an interrelated mesh for a given *IfcSpace* instance.

Several possibilities are provided by IFC2x3 model scheme to define the connection geometry and different definitions are encountered when observing IFC models generated in practice. The *IfcConnectionGeometry* for horizontal slabs, for example, is often defined as an *IfcCurveBoundedPlane* instance, which provides a closed and planar curve, as a boundary facet. However, in compliance with the model scheme, the wall connection geometry might be defined by means of an *IfcSurfaceOfLineairExtrusion* instance. In that case, the generation of the curve defining a wall connection geometry is far more complicated. Merely a prismatic surface is provided, determined by a two dimensional profile, an extrusion direction and height (Figure 3). Surely, the profile to be extruded matches the line segment where the wall connects to the flooring, but problems arise when trying to define the line segment connecting the wall to the space ceiling. Note that the extrusion height is derived from the *IfcSpace* individual representation, which is in some cases the space bounding box and therefore does not necessarily coincide with the exact shape. A strategy is presented to generate the exact shape and represent it by a closed, directed mesh.

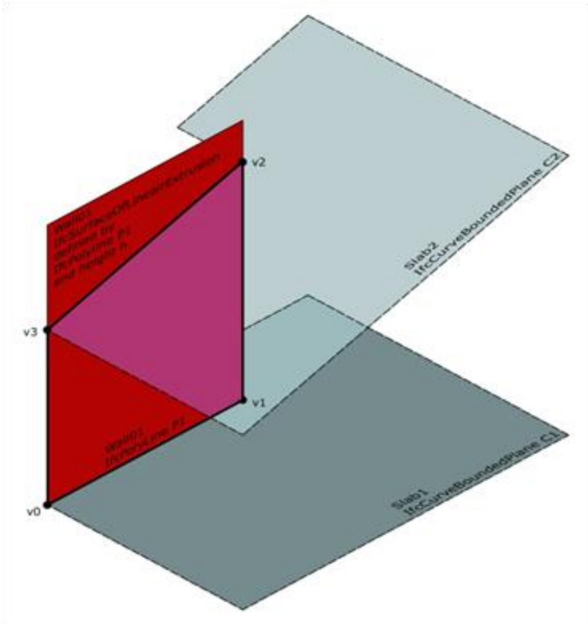


Figure 3: The intersection of the extruded surface of the wall with the slab curve defines the wall curve

Triangulating connection geometry representations

A first step consists of triangulating the curve or surface which represents the connection geometry between a bounding component and the space. Several algorithms exist to perform a triangulation, but the one preferred is the algorithm by Domiter et al. [Ref. 4.6]. This recent algorithm provides a constrained Delaunay triangulation for a planar point set by using a sweep-line paradigm combined with Lawson's legalisation [Ref. 4.7]. The algorithm simultaneously triangulates points and constrained edges resulting in a very fast and reliable procedure. The following steps are executed:

- *initialisation: sort the input points by y and x coordinate and store if a point is an endpoint of a constrained edge;*
- *generate two virtual starting points, lying below all points and with an x coordinate exceeding the minimal and maximal values of the input points;*
- *the starting points and the first point from the sorted list constitute the first triangle, the advancing front is initialised;*

- *process the next point by vertically projecting it on an edge of the advancing front. Combining the edge with the point processed delivers a new triangle and the advancing front is updated;*

- *legalise the newly found triangle by checking if the circumscribed circle contains a vertex of the neighbouring triangles. If so, swap the common edge with the other diagonal and recursively legalize the newly created triangles;*

- *generate additional triangles by connecting the point processed with the visible points on the advancing front and repeat the previous step. A point is visible when the angle between the new triangle's edge and the advancing front is less than π, for this step our implementation differs from the original algorithm where a more detailed check is performed;*

- *if the point is an endpoint of an constrained edge, the edge is inserted at this stage. By using the neighbourhood relationship in the triangle list all intersected triangles are detected and replaced by a new set which take the edge into account. This new set is generated by recursively applying the previous steps;*

- *at last the convex hull needs to be complemented and all redundant triangles, i.e. those which have one of the virtual starting points as a vertex, are removed.*

The algorithm delivers a constrained Delaunay triangulation and thus the convex hull for the input points. Since the original curve might be concave, we need to perform a last step, namely removing all triangles which violate the original boundary by applying a winding number test for each triangle. Finally, the triangle set is stored in a data structure which holds a list of triangles, each referring to the constituting vertices and connecting edges with a pointer to the neighbouring triangle, resulting in a triangulated, directed mesh for each bounding component.

Testing for mesh intersections

The triangulated curves or surfaces are combined representing the *IfcSpace* shape. However, several triangles do not coincide with the exact structural. By using for instance the *IfcSurfaceOfLineairExtrusion* entity to represent a wall, the upper boundary is completely incorrect with respect to the ceiling when the latter is not horizontal. To overcome this kind of deviations an intersection test is performed between all triangle sets originating from the different bounding components.

The algorithm used for the intersection test is based on the work of S.H. Lo and W.X. Wang [Ref. 4.8] which we use to determine the intersection line segments between two sets of triangles. The algorithm consists of the following steps:

- *establish neighbourhood relationships between triangles of each set. This step is skipped in our implementation since these relations are already generated in the previous steps;*

- *introduce a background grid by which the search for possible intersecting triangles is seriously reduced, candidate triangles are stored in a list;*

- *within the candidate list, search for intersecting pairs of triangles. The search is performed by checking the intersection of one triangle with respect to each edge of* *the second triangle. If an intersection occurs, the nature of the intersection is classified, four cases are distinguished: an intersection point P is within the intersected triangle T, P is on an edge of T, P is on a vertex of T or the intersection consists of more than one point;*

- *finally the intersection between both triangle sets is represented by loops of line segments. At this point the neighbourhood relationships are facilitated to trace connecting triangles which provide for the correct order of the line segment loops. In this process, the type of intersection previously defined indicates to which neighbouring triangle the intersection line segment extends.*

The previous steps deliver subsets of the original triangle sets which are hit by one or more intersection segments. Those triangles need to be subdivided according to the new segments, which can be seen as newly developed constrained edges for a Delaunay triangulation of the point set originating from the parent triangle vertices combined with the intersection points calculated. At this stage the algorithm explained above is called again and the original triangles are replaced with the resulting triangle sets, leading to a subdivided mesh according to the intersection curves.

A last step in defining the exact geometry for the *IfcSpace* consists in eliminating all redundant triangles for the subdivided mesh. This is done in a very straightforward way, by excluding each triangle which has an empty value for the neighbourhood property for one of its edges. A closed and directed mesh, exactly representing the *IfcSpace* internal geometry, is delivered (Figure 4).

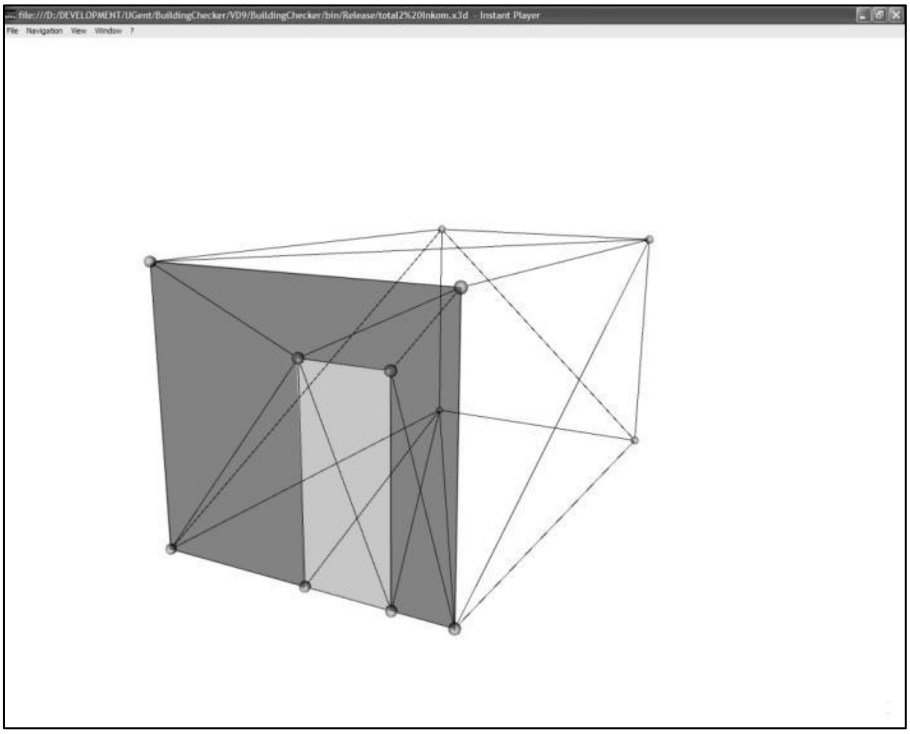


Figure 4: The closed and directed triangulated mesh, representing the internal geometry

Generating the external shape

The resulting mesh does not yet provide the data needed for the evaluations, i.e. the external volume of an *IfcSpace* or the external area for a component. Gaps appear between neighbouring spaces and the building's outside geometry is completely absent, due to the lack of geometry for all bounding constructions like walls, floors and roofs. We now describe an algorithm which inflates the *IfcSpace* internal geometry, to match its outer boundaries, by generating the boundary volume, based on the thickness of the corresponding construction component.

First of all, we need to equalise the surface normal for each triangle and point them outwards. This is achieved by a ray intersection test for each triangle, whereby the number of hits determines whether a normal is directed properly. If not, the order of the vertices is reversed.

Secondly, for each vertex of the *IfcSpace* mesh we collect all triangles of which a given vertex is a member, note that each triangle in the mesh has a reference to the *IfcConnectionGeometry* instance, and thus to the construction component it originates from. By doing so the component thickness is known, enabling us to generate a translation vector for each triangle, based on the outwards pointing normal and the thickness. Subsequently, each newly constituted translation vector is placed at the original vertex and defines a plane, since it can be perceived as a plane’s normal. Calculating the intersection for all planes generates a new vertex at the desired position, i.e. at the external junction of all construction components involved. Repeating the previous steps for all vertices in the mesh generates a new mesh representing the external dimensions for the *IfcSpace* which enables the calculation of its external volume and external area’s for the construction components (Figure 5 & Figure 6).

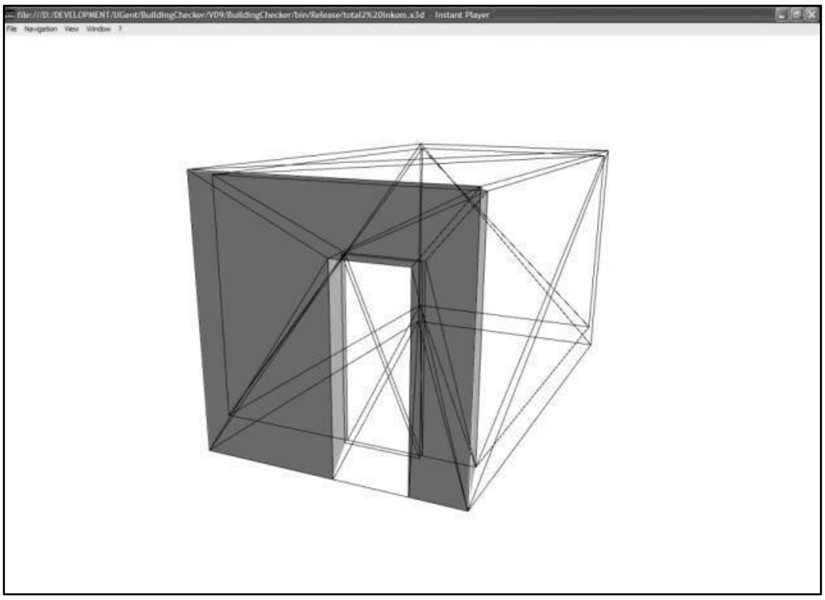


Figure 5: The inflated mesh, representing the external geometry for a IfcSpace instance

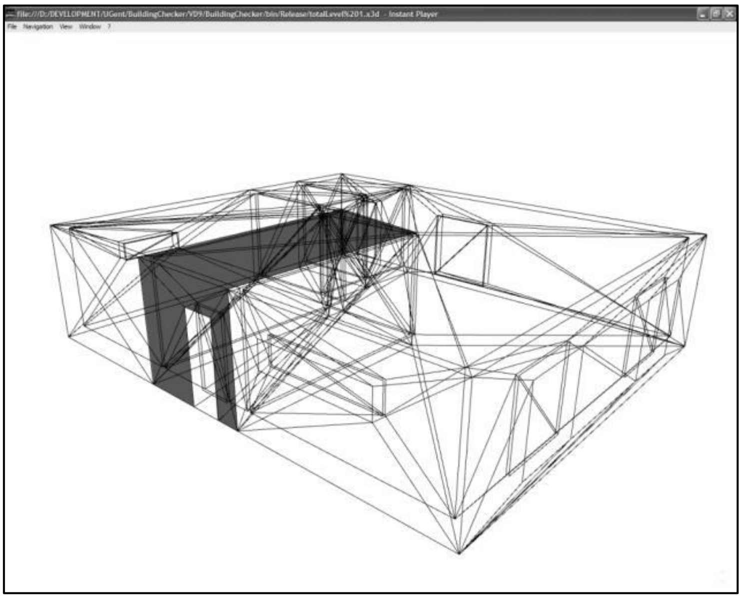


Figure 6: Collection of closed, directed, interrelated and inflated IfcSpace meshes

The prototype application

Following the investigation of the evaluation methods and the building-specific information found in the IFC format, we started with the implementation of a prototype application: the Tiatab BuildingChecker. This application enables the import of a complete BIM model through the IFC file format, upon which an automated calculation of the evaluation methods can be carried out, resulting in a relatively detailed overview of the energetic and acoustical performance of the different elements in the designed building and of the complete building itself. The main concerns thus far in the implementation of the Tiatab BuildingChecker covered the incorporation of the IFC model scheme and its possible successive versions, the extraction of the required data out of specific IFC files, the execution of the evaluation methods, and the development of a user interface with an acceptable level of clarity. The test case used is a building design modelled in Archicad12, consisting of four storeys containing several spaces with orthogonal as well as curved walls (Figure 7).

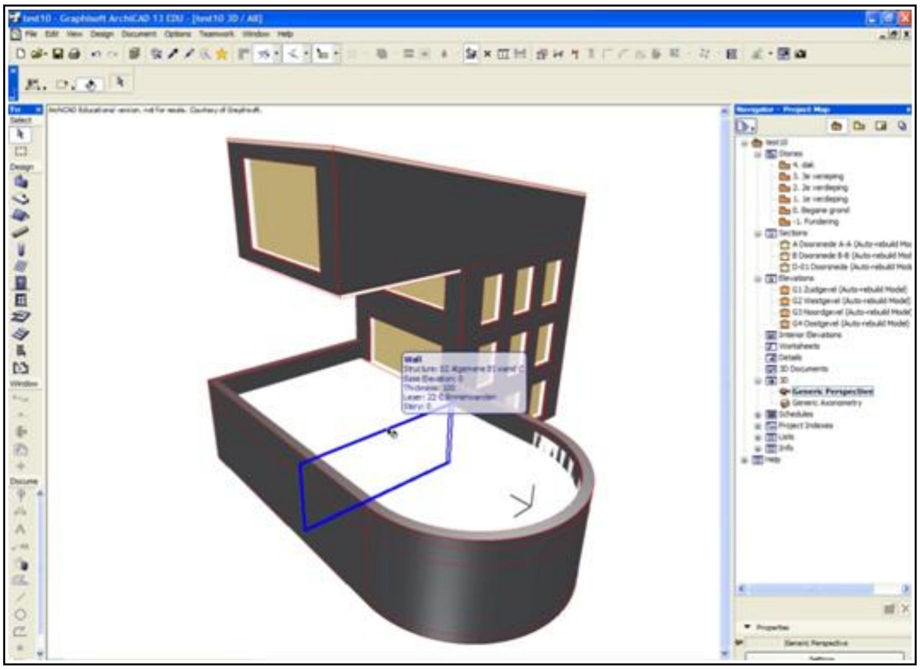


Figure 7: Test case: building design in Archicad12

We developed a procedure that translates the complete IFC2x3 model scheme, formulated in the EXPRESS language into a class library for Java or .NET. This procedure contains four steps that enable the translation of each new version of the IFC model scheme into a new, updated Java or .NET class library. The current application uses the .NET class library of the IFC scheme.

- *The EXPRESS scheme is loaded by means of an ANTLER parser, resulting in a generated abstract tree structure of the scheme;*
- *While reading the tree structure, information concerning data types, enumerations, selects and entities is stored in a set of IFC classes;*
- *An extra developed code generator translates the newly generated IFC classes into a Java or .NET class library;*
- *A dispatch table is generated defining a constructor call for each class.*

By deploying such a class library in the eventually implemented application, the import of a specific IFC file consists of a mapping operation between each IFC entity and a .NET class and calling its corresponding constructor to generate the object with its necessary relations.

Because the evaluation methods procedure itself starts from a Xml-based input files, Xml schemes have been developed comprising all required data. This intermediate step was introduced to enable the import of both model files based on the IFC standard as model files based on other formats (e.g. GbXml). For each import, all IFC objects in memory are thus iterated in order to collect the required data, which is stored into several Xml-files, containing a description of the geometry and the material layers for all construction components, completely in a space-based structure.

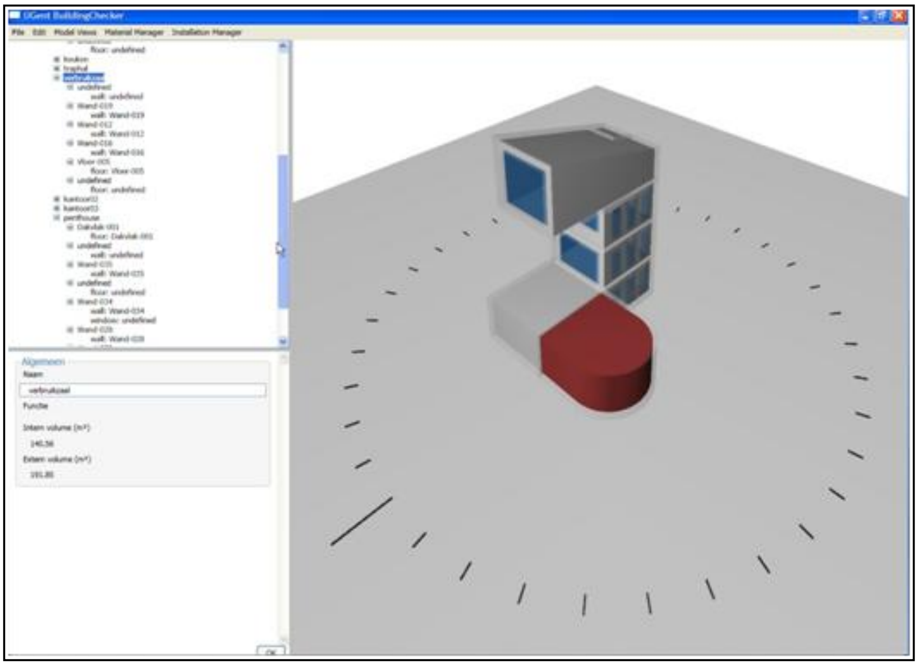


Figure 8: The Tiatab BuildingChecker application, model import

The user interface needs to be as intuitive and structured as possible to allow the desired level of understanding for designers and architects, especially those who are not familiar with similar calculation tools. Therefore we decided to split the user interface in a tree view containing the structure of the underlying building model (left in Figure 8) and a content view consisting of a 3D view. When an object is selected in the tree view on the left, the corresponding object will also appear visibly selected in the content view on the right and specific properties of the object are shown in a window at the bottom of the left pane. The result of the sample IFC import can be seen in Figure 8.

Although the IFC model scheme enables the description of a material by its physical properties or by an external reference, only visualisation properties can be found in practice. Since this information is needed in the evaluation procedure, a material database is introduced to overcome this problem. This database supplies the required properties, such as thermal conductivity and acoustic profiles per material. Once a material or material layer exists in the database it will automatically be attributed to its corresponding construction component, meaning that the assignment is a non-recurrent user intervention. A screenshot of the material library is shown in Figure 9.

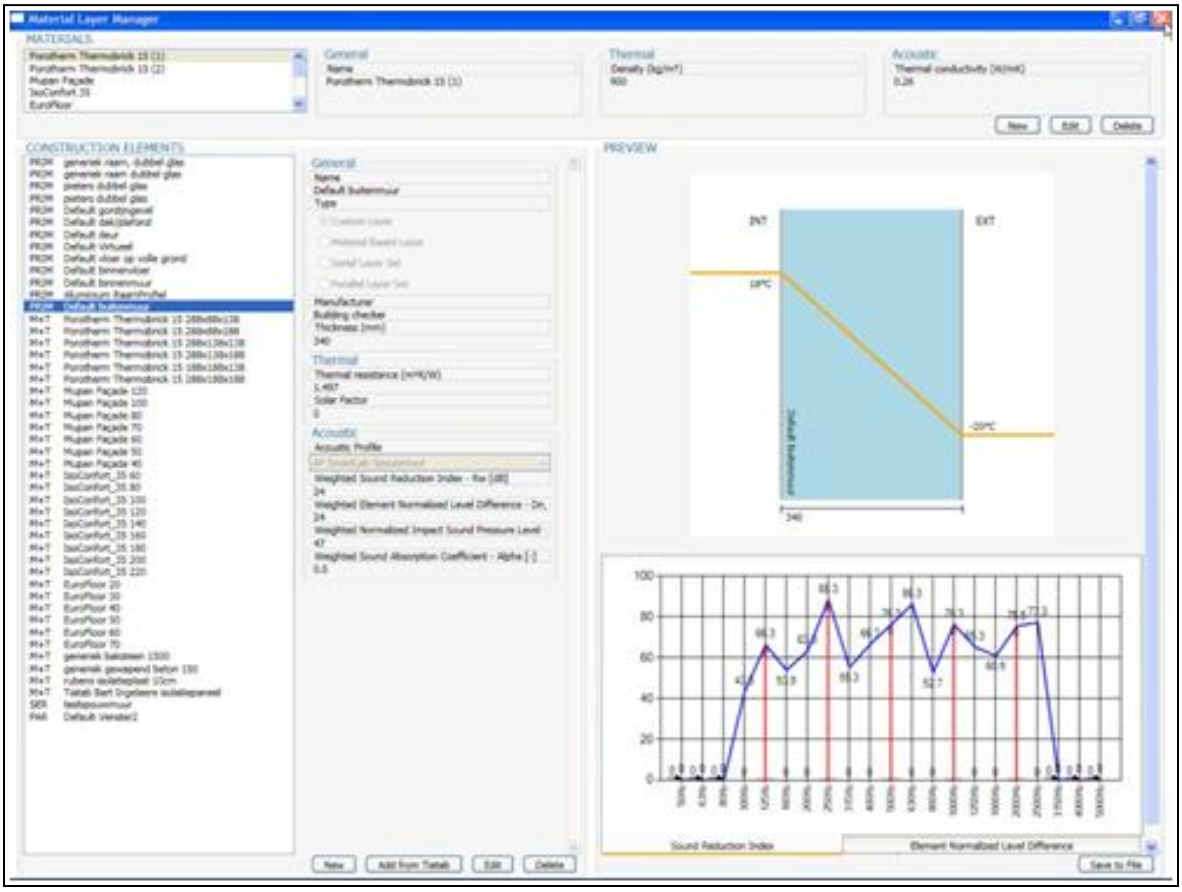
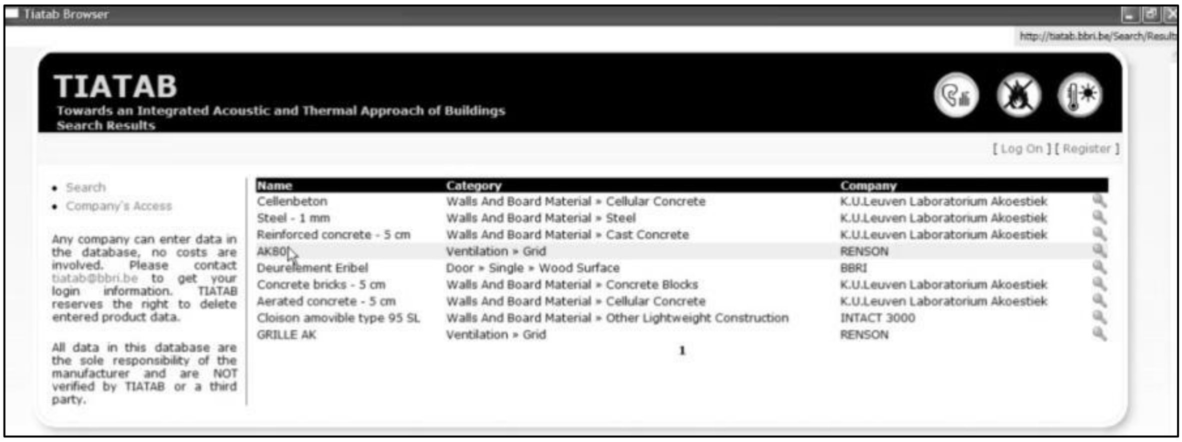


Figure 9: Tiatab BuildingChecker application, material library

The material library is a user specific collection of building materials. As stated in the introduction, the TITAB project implemented a public database providing building product information: the Tiatab Database. Import functionality is provided by the Tiatab BuildingChecker application to consult the Tiatab Database and import the product information, enabling a quick setup and maintenance of the user specific library.



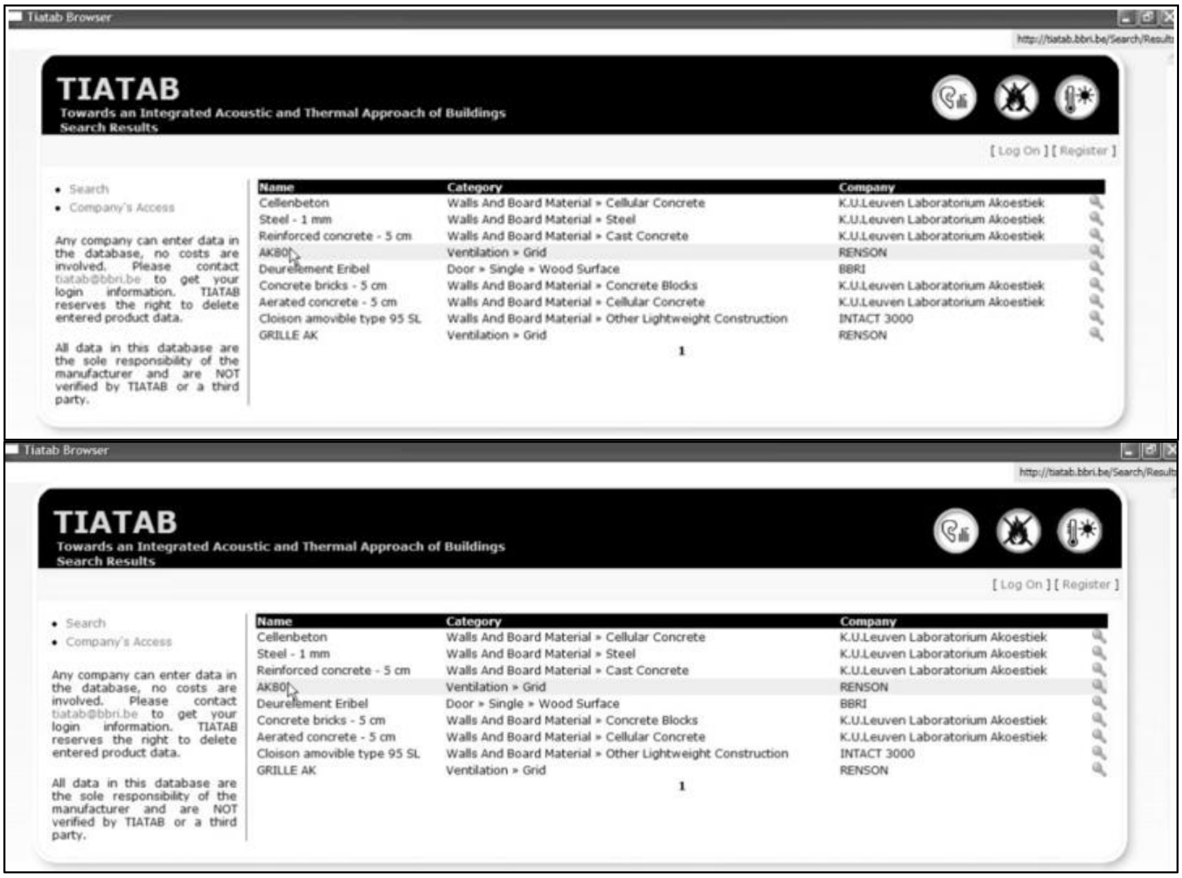


Figure 10: Tiatab BuildingChecker: import functionality from Tiatab Database

Once each space boundary instance is referenced to the corresponding materials in the library, note that this referencing operation is a nonrecurring step, the geometrical transformation algorithms can be executed, i.e. triangulating the boundary curves, constituting the closed, directed and inflated space meshes.

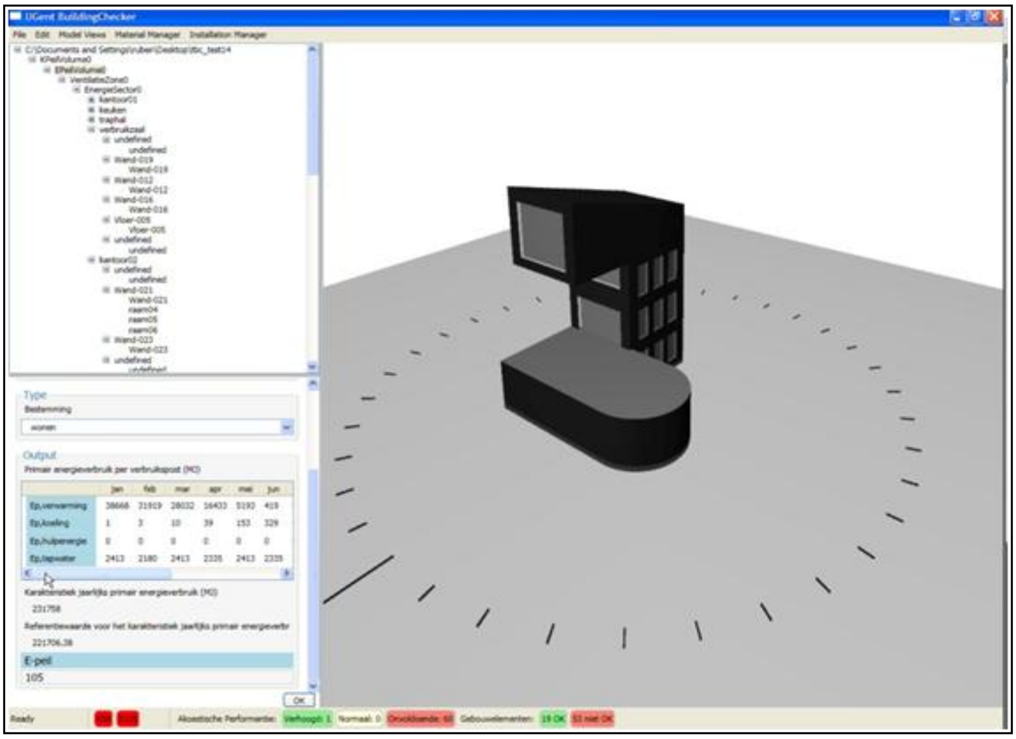


Figure 11: Tiatab BuildingChecker application, energy view with results

Finally, both energetic and acoustical evaluations need non-architectural information such as heating system efficiency, solar screens performance, the position with respect to roads as sound sources,… Defining this kind of information is the last step before energetic and acoustical evaluations are executed. The results of both evaluations are shown by switching between an "energetic" or "acoustical" view of the building model (Figure 11 & Figure 12).

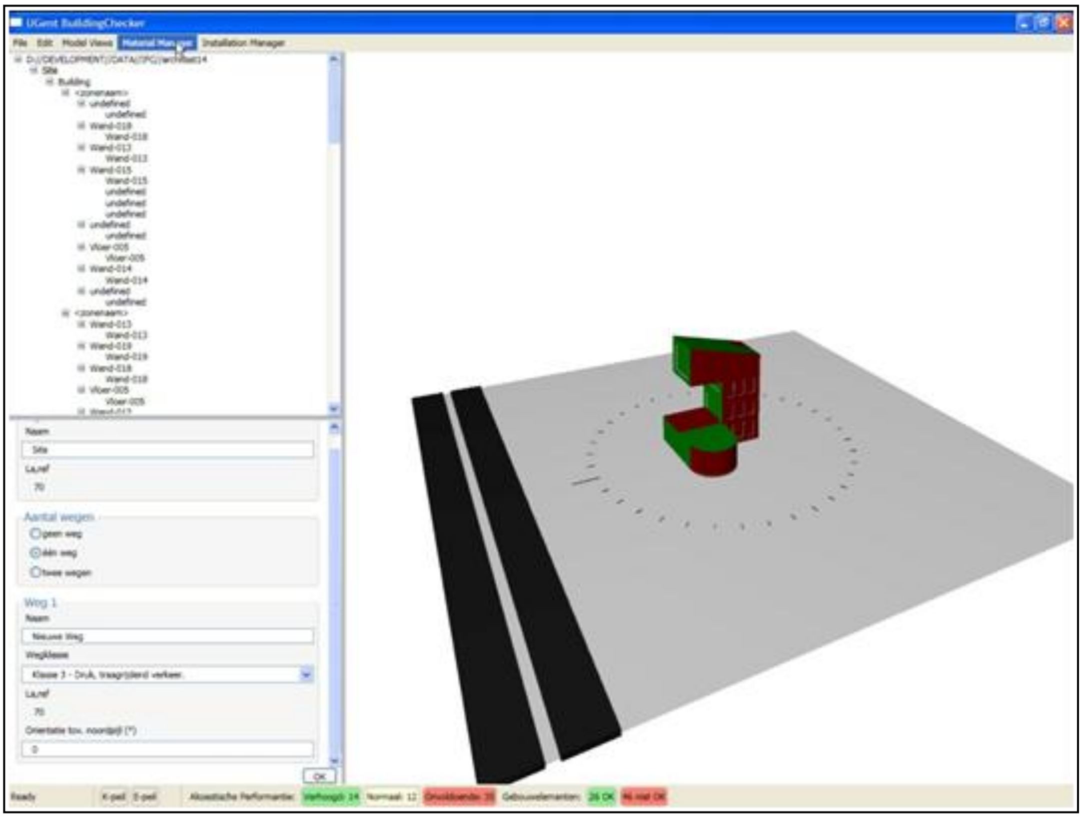


Figure 12: Tiatab BuildingChecker application, acoustical view with results

4. E. THE TIATAB DATABASE

Introduction

The availability of acoustic and thermal data of building elements is a necessity in this integrated approach. This information is needed to estimate the overall performance and to be able to apply correct building details in the project. Nowadays it is a difficult task to obtain this information: sometimes one can find data about the thermal performances on the website or technical documentation of the producer, but then very often the acoustic information is missing. And vice versa: for building elements with specific acoustic applications, the thermal information will sometimes be missing. In most cases, the data is missing because it simply hasn't been measured. Very often, it is an indication that the manufacturer has not been thinking about this integrated approach.

A database was created on the internet. It allows the introduction of acoustic, thermal and fire performance data and can be read directly by the BIM modeller as detailed in the previous chapter. Filling in this database will be a task point of the European COST action TU0901.

The principal philosophy of the database is that the data are entered by the companies themselves. As such, they are responsible for their own entered information and can change or update these at any time. The advantage of this is that the database can run without someone of the research partners being obliged to spend time entering and correcting all these data. This also means that there is no limitation in the possible growth of the database.

The reliability of the data is as such no more or no less than what can be found in the classical printed technical information of the companies. Some extra software tools were added that are able to detect certain input errors (for example there is an automatic tool recalculating acoustic single ratings from the entered spectra and comparing it with the input single ratings). Test reports can also be uploaded to the database. Weblinks to the company or product website can be added to the database.

We hope that as more companies introduce data, this will create an automatic incentive to be on it for all the other companies as well. Finally, it should push manufacturers to do recent acoustic, fire and thermal tests on their products.

The work on the database was a very extensive job. Details about this software can be found in the manual on the site.

Technical specifications and login

The database is an Oracle Database 10g Release 10.2.0.1.0. The main reason for this choice is that BBRI is using the same database for its data storage. Stored procedures and packages were used for data handling. The connection between the database and the web application is provided by the Oracle Data Provider for .NET (ODP.NET). The library features optimized ADO.NET data access to the Oracle database. The build-in library from Microsoft is deprecated and is less efficient. The used version is 11.2.0.1.2. The web application is running on a Windows 2003 Server with IIS 6. The web application is built in ASP.NET according to the Model-View-Controller principle using the ASP.NET MVC 2 library. This reflects in clearer and efficient coding. The main programming language is the object-oriented language C# combining with the .NET framework 3.5. Logging is handled bij NLog. NLog is an open source free logging platform with rich log routing and management capabilities. The web application is designed according to common techniques, XHtml 1.0 and CSS 2.0. The JQuery javascript library was used to handle all the javascript requests. [Ref. 4.9 to 4.11]

Tiatab dynamically generates the web pages. Tiatab is designed for a minimum screen resolution of 1024 x 768 pixels.

You access Tiatab through a web browser. Enter the Tiatab URL (http://tiatab.bbri.be/) in the address bar of your web browser. The search page will be displayed.

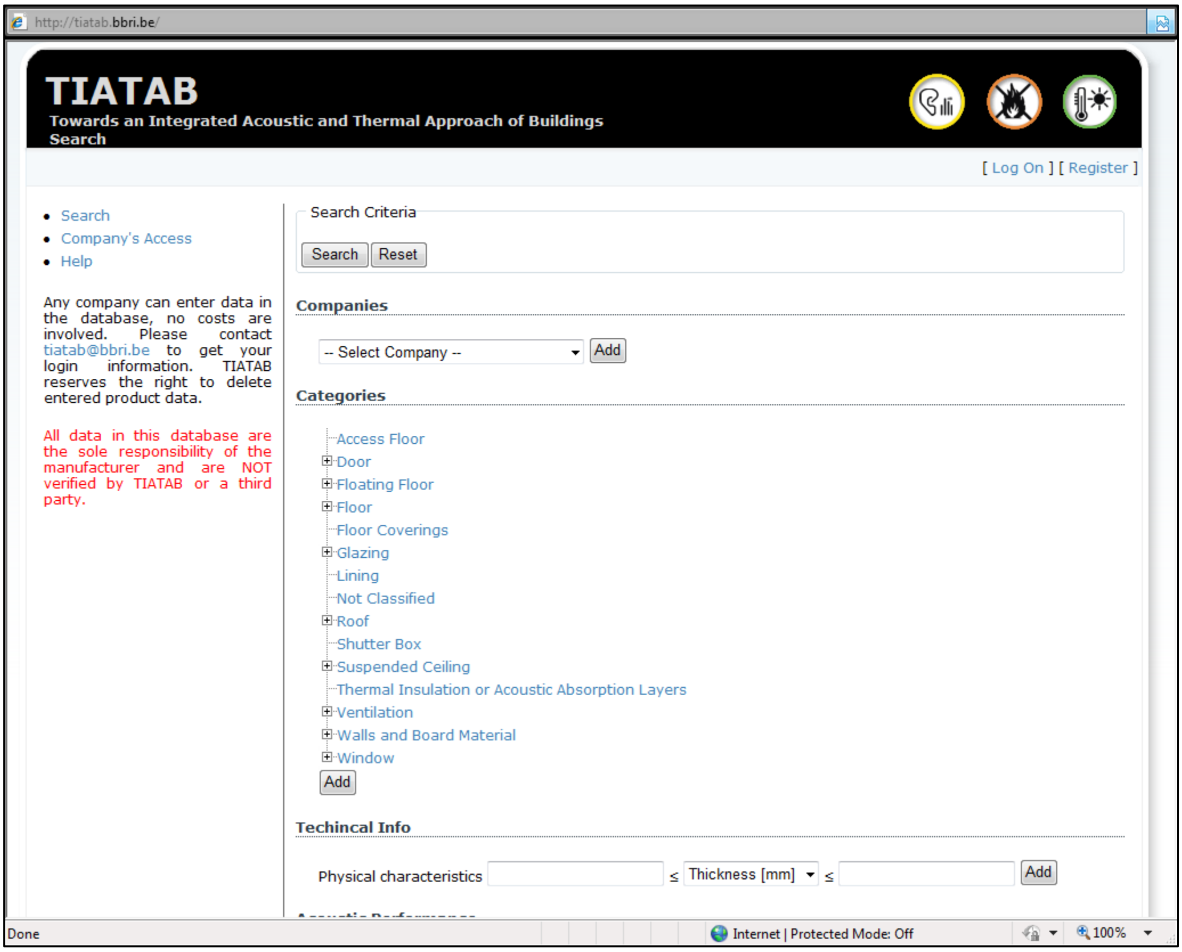


Figure 13: Tiatab Homepage

Registering an account on Tiatab is a simple and straight forward procedure. You need to fill out some important details such as selecting a username, entering your first name, last name, your e-mail address and desired password. You also need to fill out the details of your company (name, address, telephone and e-mail address). Once you have completed all of the fields on the registration page, clicking the Register button will complete the process. You will be sent an e-mail to the address you specified with a link to finalise the registration. Click the link to activate your account and to receive your account details.

When you visit Tiatab (http://tiatab.bbri.be/), the Search module displays on the screen. The search module provides you with various fields to filter the products in the application. The search results can also be mutual compared.

Inserting a new product

When you click on the link “Create New Product” the screen displays the input page. The page contains 4 tabs to ease the creation of a new product.

<u>The first tab contains the general details</u> of the product, like category, name or technical info.

You must at least select a category and fill in a product name before advancing to the next tab. After filling in the fields press the “Next Page” button to go to the next tab.

The second tab is the “Acoustic Performance” tab. Here you can add acoustic performances to your product. Click the dropdown list to choose a specific performance. Every performance can only appear once. Possible performances:

- *Element Normalized Level Difference - Dn,e*
- *Normalized Flanking Level Difference - Dn,f*
- *Normalized Impact Sound Pressure Level – Ln*
- *Reduction Of Impact Sound Pressure Level – ΔL*
- *Sound Absorption Coefficient – α*
- *Sound Reduction Improvement Index (Heavy walls) – ΔR*
- *Sound Reduction Improvement Index (Light walls) – ΔR*
- *Sound Reduction Index – R*
- *Suspended-Ceiling Normalized Level Difference - Dn,c*

After choosing a specific performance a new form will display on the page. On the left you can fill in the values by frequency. A graph will appear on inserting these values. The filled ratings will be compared on submit with the calculated ratings. A green or red bullet will appear when both ratings accord or not. Optionally quality labels and test references can be added to the performance. After filling in the fields press the “Next Page” button to go to the next tab.

The third tab is the “Fire Performance” tab. Here you can add fire performances to your product. Click the dropdown list to choose a specific performance. Possible performances:

- *Fire Reaction*
- *Fire Resistance*
- *Roof Performance in respect to exterior fire*

Optionally quality labels and test references can be added to the performance. After filling in the fields press the “Next Page” button to go to the next tab.

The fourth and last tab is the “Thermal Performance” tab. Here you can add thermal performances to your product. Click the dropdown list to choose a specific performance. This performance can only appear once. Possible performances:

- *Thermal Conductivity*
- *Thermal Glazing Performance*
- *Thermal Resistance*
- *Thermal Transmittance*

Optionally quality labels and test references can be added to the performance. Click the “Create” button to submit your product.

4. F. CONCLUSION

Emerging BIM applications combined with the interoperability of the Industry Foundation Classes trigger unique possibilities and advantages for architectural design and construction. The development of downstream applications for calculation and simulation purposes based on BIM technology allows a highly improved evaluation of preliminary and detailed architectural design projects. At this point, this methodology or work process is mainly being used by national and international (research) initiatives and large-scale companies. In order to bring BIM usage on a larger scale level, further improvements need to be determined and developed for the communication of information between different partners in the design process and the application they use.

This research is addressing this issue by investigating the IFC compliance with delivering the information needed to perform an energy and acoustic performance calculation. As a basis for performing such a calculation, we started from the Energy Performance Regulation, which is mandatory in Flanders for newly constructed and renovated buildings as well as the new European acoustic standard. These regulations impose the qualification of the starting from explicit building characteristics. The regulations were analysed for the information that could be obtained from a BIM model. All required building-specific information was extracted from the formulas in which this information is used. This required information was then summarised to enable comparison with accessible information sources and their corresponding possibilities to communicate this information.

A brief and schematic overview is then given of the ways in which building-specific information is stored in a regular BIM model and the ways in which this information is accessible from within external calculation software. Since maintaining a maximal level of interoperability forms the highest priority in our research, we selected what came out as the most interoperable communication method, namely the Industry Foundation Classes.

Research has then focused on the applicability of IFC to store and deliver the building-specific information needed to perform the calculation. This has resulted in advantageous workflows, but also in certain limitations. In order to comply with IFC and the calculation methods, certain workarounds needed to be developed in the form of extra algorithms. These workarounds are documented in the report.

To be able to use the models, technical data that can be easily imported is a necessity. During the project, the Tiatab database was developed. Manufacturers can ask for a password and can then themselves introduce technical data (acoustic, thermal, fire performance, etc.). The Tiatab database can easily communicate with the developed BIM software.

The report finally documents the implementation of an application as an alternative to the manual workflow an architect needs to go through if he wants to comply with the EPR and acoustic regulations. This application is able to import specific IFC files and interpret its information. It automatically acquires the information needed and performs the calculations. The results of the calculation are then displayed through a user-friendly interface, to enable a designer evaluate his design and immediately make improvements to his model. This application was tested in a case-study using an exemplary BIM model. The overall functionality of the communication process from BIM to the application is briefly analysed and the main resulting concerns are outlined by the authors.

Future work will focus on fine-tuning the EPW application and testing it against a larger set of BIM models, stemming from different environments.

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5. Determination of default values for the sound insulation indices of monolithic construction elements and double walls

5. A. INTRODUCTION

This text reports on the background of a database concerning default values for the airborne and impact sound reduction indices of monolithic construction elements.

Thermal and acoustical problems are frequently considered in a global building physics approach. This leads to regular misunderstandings. Thermal and acoustical properties are named together, sound absorption and sound insulation are regularly mixed up, and frequently one hears people talk about the acoustical wall resistance (for airborne sound insulation). So, as an introduction, let us first consider thermal properties in relation to acoustical properties.

As is well known, thermal properties of a material layer, have a direct relation to a specific thermal material property as thermal conductivity: the thermal resistance of a layer is given by dividing thickness of the layer by its thermal conductivity. But in relation to sound insulation for instance, one can say that no such specific acoustic isolation material property exists. The acoustic quality of construction is rather depending on combinations of several mechanical material properties: surface weight, bending stiffness, global damping,... .Also, thermal properties of combined elements and of three-dimensional details can be derived in a strict respect of the fundamental heat flow equations.

One can certainly state that acoustics from the point of view of calculation is much more uncertain. This has to do with the physical phenomena: the airborne sound reduction index for instance, relates to the sound power transmitted by element or by a global construction in relation to the sound power incident on the separating element. The definition is reduced to a measurement formula based on the measurement of the level difference between the spatially averaged squared sound pressure in the emitting and in the receiving room in a transmission setup. The impact sound insulation is derived from the sound power radiated by a floor and wall mechanically excited by a standardised operation of the ISO standard tapping machine. Again the sound power is derived from the measurement of the sound pressure level in the receiving room.

All the quantities make use of idealised or simplified relations, so-called diffuse field conditions. However the sound fields are in fact related to the modal properties of the air volumes, this is why always a spatial sampling will be needed. Already this fact, will introduce inherent uncertainties for the measurement results: which and how many positions of the microphone?

In a sound transmission problem the reality is also quite complicated and frequency dependent. To illustrate this point we present a result of a full calculation of the sound transmission from point to point in the transmission set up separated by a single glass pane of 1 cm thick (Figure 14). The result is strongly frequency dependent. This is the physical reality, but due to the relevance for hearing not all of this information is relevant. The bandwidth of human hearing is in a first approach proportional to the frequency. So it makes sense to collect the energy together within one third octave bands which come close to the bandwidth of human hearing (at least above 500 Hz). The results of the dark blue bumpy line reflect this interpretation. It can also be proven that the results are in a way depending on the details of the measurement opening (niche effects, positioning of the opening). One has tried to deal with all of these influences by specifying the test conditions and test procedures.

The most important message however, is that the airborne sound insulation quality results from a specific mounting of a single test panel and differences are not simply related to material properties.

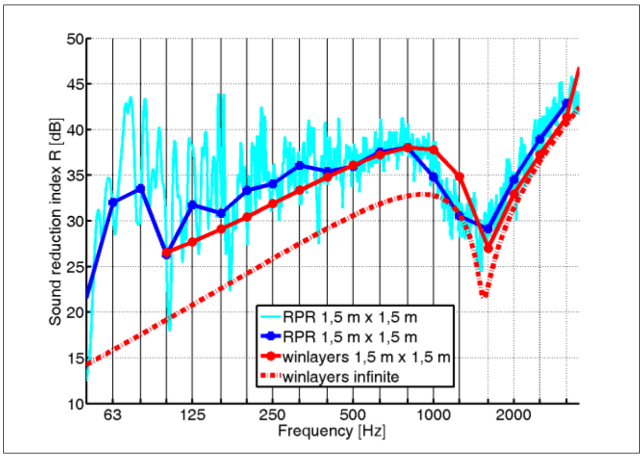


Figure 14: Sound Reduction Index between two rooms with a baffled glass pane of dimensions 1.5x1.5 m². The results are presented in narrow bands and in the regular third octave bands (blue line) / (the red line concerns infinite plate model, the full red line concerns adaptations to finite dimensions [calculation results by Arne Dijckmans, Laboratory of Building Physics, K.U.Leuven].

So it should be clear that the step from simple mechanical material properties as density, thickness, bending and shear stiffness, material damping,... to any sound insulation quality will depend on many more elements. Data reduction and measurement specifications help to reduce the measurement uncertainties. But mounting differences may play on the internal damping and so on the final result. This is certainly the case for heavier walls: losses to the boarders will depend on the characteristics of the mounting and of the surface weight of the surrounding elements. Figure 15 shows 12 results on a 440 kg/m^2 Ca-Si blockwall from a very detailed Inter-Laboratory study from the late 90’s. The single number ratings vary over 7 dB (54-61 dB)! However influences like workmanship, measuring procedures where at most minimised (Schmitz, Meier, & Raabe, 1999) and (Meier, Schmitz, & Raabe, 1999).

Taking this into account one has to question specific values from a specific laboratory and comparison with standard values will always be advised. In this text we first report about the way that "default" values for monolithic constructions where obtained for input into the database. Next, the even more complicated double and multilayered constructions are considered.

In situ the practical situation will even be more complicated: sizes of panels, sizes of rooms, boundary conditions, flanking transmission will intervene. So from the beginning we have to accept a spread on measurements and certainly on the predictions.

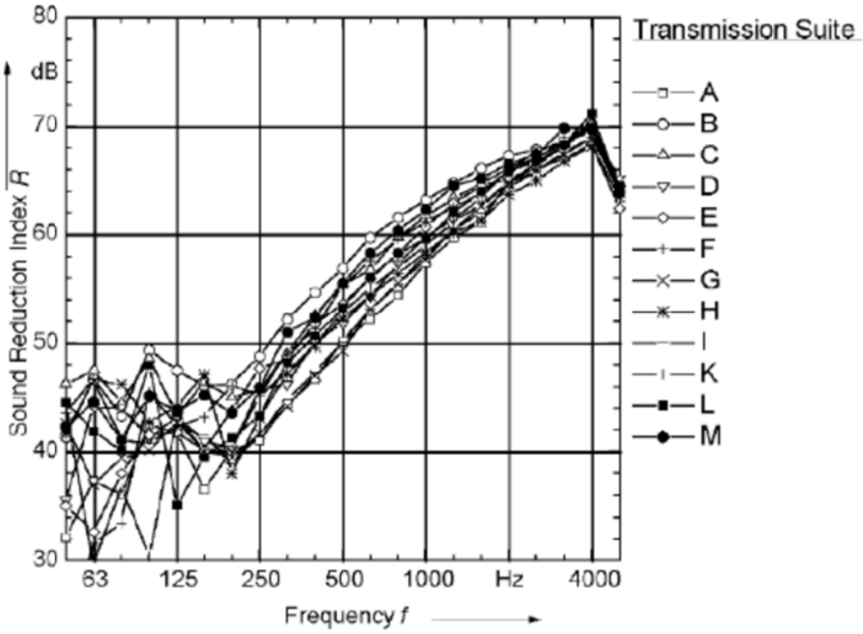


Figure 15: The Sound Reduction Index of a similar wall in 12 different transmission suites with rigid connections (PTB comparison measurements)

5. B. DETERMINATION OF DEFAULT VALUES FOR THE SOUND INSULATION INDICES OF MONOLITHIC CONSTRUCTION ELEMENTS

Background to the prediction of single wall/floor sound reduction index and impact sound insulation index

The physical background concerning airborne and impact sound insulation is discussed on several places, we refer to (Vermeir, 1999). Concerning the predictions of global sound insulation several consensus documents exist on international level, grouped as a series of CEN-ISO documents, which were introduced as standard documents in the EN member states. Interior sound insulation is dealt with in the documents NBN EN ISO 12354-1: 2000 and NBN EN ISO 12354-2: 2000. We cite and annotate the formulas which are given.

Prediction of the airborne sound insulation of monolithic partitions

In relation to the airborne sound insulation R three frequency ranges have to be considered: below, around and above the limit frequency $f_{\lim}$.

The following formulas are introduced:

$R = -10\lg\tau$ (1)

With R for the airborne sound insulation in dB, and τ the transmission factor [-].

The limit frequency is the lowest possible frequency for which free bending waves on the plate can have the same wavelength as the trace of the wavelength of a wave in the air on the plate. For infinite extension of the plate this limit frequency will be related to grazing incidence of an airborne sound wave. In this case the limit frequency is related to the properties of the plate, in the following way: $f_{\lim} = \frac{c_0^{\ 2}}{1,8 c_L h}$.(2) With c_L as the longitudinal wave speed. For a plate with infinite extension c_L is given as $c_L = \sqrt{\frac{E}{\rho(1-\mu^2)}}$ (3), with μ as Poisson's modulus. μ is approximately equal to 0,3 for structural materials as brick, metal, glass, so $c_L = \sqrt{\frac{E}{\rho}}$ (4) can be considered as an acceptable approximation.

<u>*For the frequency region above the limit frequency*</u> the airborne sound insulation is resonance controlled, this means that the interaction between the modes on the plate and the modes in the room will determine the resulting airborne sound insulation. The formula reads: $\tau = \left(\frac{2\rho_0 c_0}{2\pi f m''}\right)^2 \frac{\pi f_{gr} \sigma^2}{2 f \eta_{tot}} \quad \text{for} \quad f > f_{\lim}$ (5)

In this formulation (5) $\rho_0 c_0$ is equal to the characteristic wave propagation impedance in the air [nominal value 400 mks Rayl], f [Hz] is the frequency, m'' [kg/m^2] is the surface weight, σ [-] is the radiation factor for free bending waves and η_{tot} [-] the equivalent (total) mechanical damping.

<u>*In the limit frequency region formula*</u> (6) is proposed: $\tau = \left(\frac{2\rho_0 c_0}{2\pi f m''}\right)^2 \frac{\pi \sigma^2}{2\eta_{tot}} \quad \text{for} \quad f \approx f_{gr}$ (6)

In addition to the information in NBN EN ISO 12354-1: 2000, E. Gerretsen specifies in an internal note (Gerretsen E., 2002) to apply following additional option: the frequency span around the limit frequency is taken as: $f_{\lim}.0,9 < f < f_{\lim}.1,4$ and he proposes to take $\sigma = 1,2$ in this region.

<u>*Well below the limit frequency*</u> the sound insulation is mass controlled, but a series of adaptations is needed to take into account the finite dimensions.

$$\tau = \left(\frac{2\rho_0 c_0}{2\pi f m''}\right)^2 \left(2\sigma_{forced} + \frac{l_1 + l_2}{l_1^{\ 2} + l_2^{\ 2}}^{\ 2} \sqrt{\frac{f_{\lim}}{f}} \frac{\sigma^2}{\eta_{tot}}\right) \quad f < f_{\lim} \ (7)$$

In equation (7) appears σ_{forc} as the radiation factor for forced waves. In principal this quantity tends to 1 for infinite plates. l_1 and l_2 [m] are the dimensions of the wall with $l_1 \geq l_2$.

Following formulas are proposed for σ_{forc}:

$$\sigma_{forc} = 0,5[\ln(k_0\sqrt{l_1 l_2}) - \Lambda]; \sigma_{forc} \leq 2$$
$$\Lambda = -0,964 - (0,5 + \frac{l_2}{\pi l_1})\ln\frac{l_2}{l_1} + \frac{5 l_2}{2\pi l_1} - \frac{1}{4\pi l_1 l_2 k_0^{\ 2}} \qquad (8)$$

With k_0 being the wave number, equal to $\frac{2\pi f}{c_0}$ [rad/m].

For free bending waves the following formulas are proposed:

$$\sigma_1 = \frac{1}{\sqrt{1-\frac{f_{\lim}}{f}}} \text{ (9)}; \quad \sigma_2 = 4l_1l_2\left(\frac{f}{c_0}\right) \text{(10) and } \sigma_3 = \sqrt{\frac{2\pi f \;\; l_1+l_2}{16c_0}} \text{ (11).}$$

Further on one also relates to relative value of f in relation to the fundamental vibration mode f_{11}. With the following relationship: $f_{11} = \frac{{c_0}^2}{4f_{\lim}}\left(\frac{1}{l_1^2}+\frac{1}{{l_2}^2}\right)$ (12).[1]

Depending on the position of f_{11} in relation to $f_{\lim}$ one uses following relations:

If $f_{11} \le f_{\lim}/2$ then:

If $f \ge f_{gr} : \sigma = \sigma_1$;

if $f < f_{gr} : \sigma = \frac{2 \;\; l_1+l_2}{l_1l_2}\frac{c_0}{f_{gr}}\delta_1+\delta_2$ (13) with:

$$\delta_1 = \left(\frac{1-\lambda^2 \;\; \ln\frac{1+\lambda}{1-\lambda}+2\lambda}{4\pi^2 \;\; 1-\lambda^2 \;\; ^{1,5}}\right) \text{(14) with } \lambda = \sqrt{\frac{f}{f_{gr}}} \text{ (15) and}$$

$$\delta_2 = \frac{8{c_0}^2(1-2\lambda^2)}{{f_{gr}}^2\pi^4 l_1l_2\lambda\sqrt{1-\lambda^2}} \text{ (16);}$$

if $f > f_{gr}/2$ then $\delta_2 = 0$ else (16);

if $f < f_{11} < f_{gr}/2$ and $\sigma > \sigma_2 : \sigma = \sigma_2$;

always: $\sigma \le 2,0$.

[1] This is exactly the same as the more common formula $f_{mn} = \frac{\pi}{2}\sqrt{\frac{Eh^3}{12\rho h}}\left[\left(\frac{m}{l_1}\right)^2+\left(\frac{n}{l_2}\right)^2\right]$ with $m = n = 1$.

If $f_{11} \leq f_{gr} / 2$ then:

if $f < f_{\lim}$ and $\sigma_2 < \sigma_3$: $\sigma = \sigma_2$;

if $f > f_{\lim}$ and $\sigma_1 < \sigma_3$: $\sigma = \sigma_1$;

else: $\sigma = \sigma_3$;

always: $\sigma \leq 2{,}0$.

This group of formulas is a result of combining several resources in the literature about this subject. The formulas (8) refer to (Sewell, 1970), the formulas (9) and following are proposed in (Maidanik, 1962). All formulations are cited in the informative annex B of NBN EN ISO 12354-1: 2000. Radiation is also influenced by surrounding walls and other formulas could be applied as e.g. (Novak, 1995).

Further, one can also consider the effect of "thick plate" wave propagation and adapt the limit frequency $f_{\lim}$ to an effective limit frequency $f_{\lim,eff}$ based on the adapted the bending propagation wave speed (Cremer & Heckl, 1988), (Gerretsen E., 1986), (Ljunggren, 1991).

The proposed formula reads:

if $f < f_p$ $$f_{\lim,eff} = f_{\lim}\left(4{,}05\frac{hf}{c_L} + \sqrt{1+\left(4{,}05\frac{hf}{c_L}\right)}\right) \quad (17)$$

if $f \geq f_p$ $$f_{\lim,eff} = 2 f_{\lim}\left(\frac{f}{f_p}\right)^3 \quad (18)$$

with $f_p = \dfrac{c_L}{5{,}5h}$ (19); h the thickness [m], c_L is the longitudinal wave speed in the plate's material [m/s].

Comments on alternative approaches

In the acoustics community different alternatives are existing as computer programs like BASTIAN, INSUL, REDUCT, ENC, WINFLAG, ACOUBAT, WINLAYERS, DnT. Many have different backgrounds and show significant differences. The first 5 are compared in some detail in (Cambridge, 2006). Substantial differences between results were found. But one can at least confirm the programs based on the approach describe above. (Bastian) delivers reliable results for single walls.

(Hongisto, 2006) reflects a study on the performance of predictions for double walls' airborne sound insulation. The conclusions read: "*The average prediction errors for individual frequencies were as high as 20 dB (Rw: 15 dB) for most of the models, while it was less than 10 dB (Rw: 5 dB) for the best models. None of the models was sufficiently accurate in all four categories. There is an obvious need to develop a new model, which can be reliably applied to arbitrary double and multilayer walls. In the present situation, the most accurate model should be selected according to the type of the double wall.*"

It should be clear from this that no superior model exists. We concluded to use results for single walls as derived in 5.B.2.

Prediction of the impact sound insulation of monolithic partitions

The European Standard NBN EN ISO 12354-2, 2000 shows a prediction method based on literature like (Vermeir, 1999). Impact sound levels are created with the standard tapping machine working on a floor under test. In the lab, with flanking transmission suppressed, the sound will depend on the characteristics of the floor (density, thickness, material properties, global damping) but also on the characteristics of the excitation. In fact a contact layer (carpet, floor covering, floating floor) will change a lot to the force input.

This is expressed by the formula from Annex B:

$$L_n = L_F + 10\lg\frac{\mathrm{Re}(Y)\sigma}{m''} + 10\lg\frac{T_s}{[1s]} + 10,6\,\mathrm{dB} \quad (20)$$

With: L_n the normalized impact sound level in the receiving lab room; Y the surface averaged floor mobility; σ the radiation factor for free bending waves; m'' the mass per unit area [kg/m^2]; T_s the structural reverberation time [s].

Only in the case of solid monolithic layers with a high enough input impedance (massive floors with 'hard' impact conditions) the formula (20) can for one third octave bands be represented as:

$$L_n \approx 155 - 30\lg\frac{m''}{[1\,\mathrm{kg/m^2}]} + 10\lg\frac{T_s}{[1\mathrm{s}]} + 10\lg\sigma + 10\log\frac{f}{f_{ref}}[\mathrm{f_{ref}} = 1000\ \mathrm{Hz}]\ (21).$$

Preliminary calculations and tests

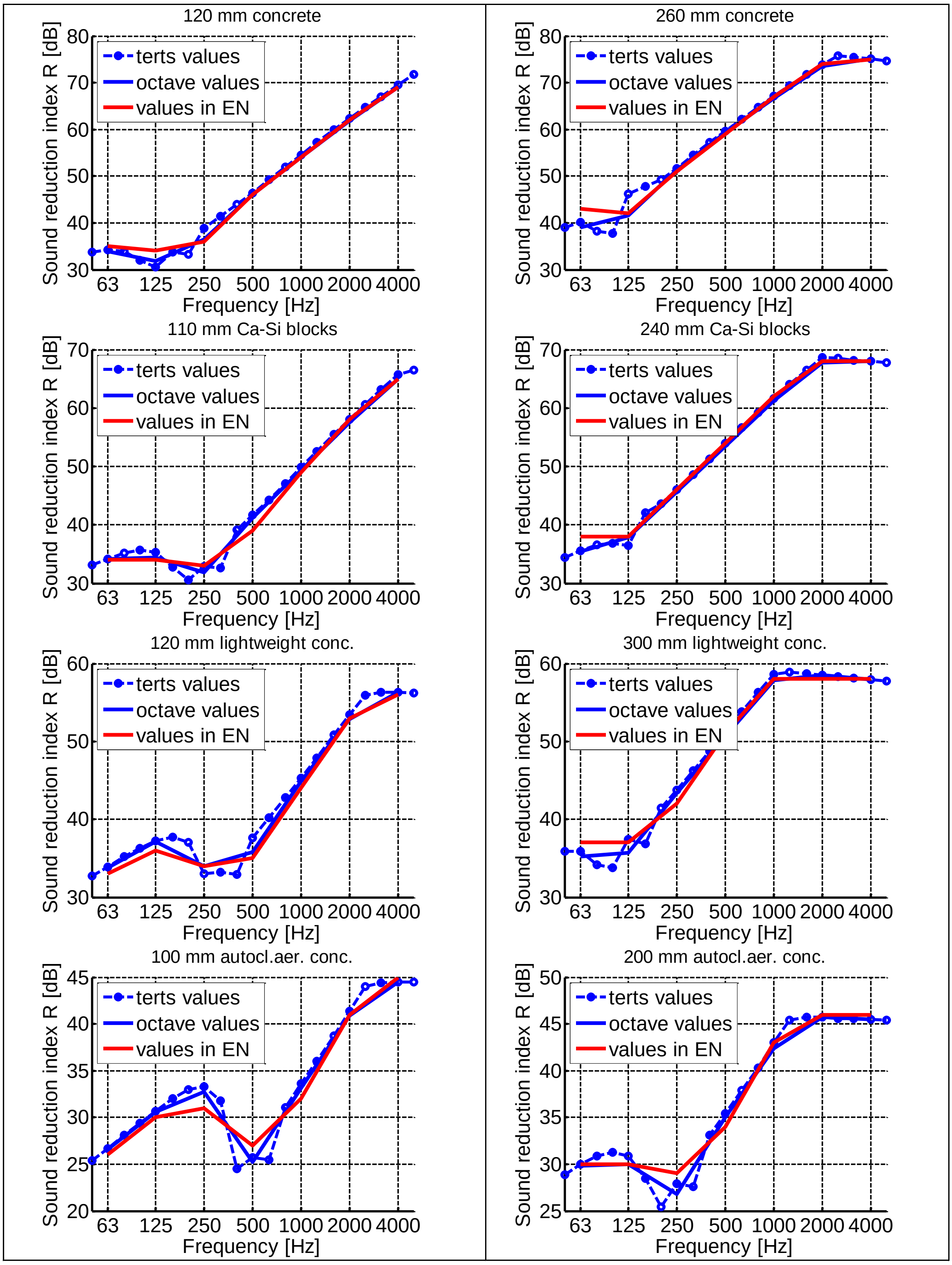
For this project we transposed the preceding algorithms to a Matlab-code. In order to allow comparison to the examples mentioned in NBN EN ISO 12354-1: 2000 we used exactly the same material data as in the document.

	Mass density [kg/m3]	Longitudinal wave speed [m/s]	Damping [-]	Equivalent E-modulus [Pa]
Reinforced concrete	2300	3500	0,006	2,8 E10
Sandlimestone	1750	2600	0,015	1,2 E10
Lightweight concrete	1300	1700	0,015	3,8 E9
Aerated concrete	650	1400	0,01	1,3 E9

Following calculations are compared:

120 mm	Reinforced concrete
260 mm	Reinforced concrete
110 mm	Ca-Si blocks
240 mm	Ca-Si blocks
120 mm	Lightweight concrete
300 mm	Lightweight concrete
100 mm	Autoclaved aerated concrete
200 mm	Autoclaved aerated concrete

On the next table the results of the comparison of our calculated results and the (also calculated) results in EN are listed. We considered the agreement as sufficient.



Concerning impact noise, as an example we applied formula (21) for a concrete floor with a thickness of 10 cm and a 2 cm thick finishing layer: surface weight:

$$2300.0{,}1+1900.0{,}02=268\,\mathrm{kg/m^2}$$

Following $\eta_{tot,lab} \approx \eta_{\text{int}} + \frac{m''}{485\sqrt{f}}$ (formula C.5 of (NBN EN ISO 12354-1, 2000)).

So at 1000 Hz: $\eta_{tot,lab} \approx 0,005 + \frac{268}{485\sqrt{1000}} = 0,023$.

$$L_n \approx 155 - 30\lg\frac{268}{[1\,\text{kg/m}^2]} + 10\lg\frac{\frac{2,2}{1000 \cdot 0.023}}{[1\text{s}]} + 10\lg 1 + 10\log\frac{1000}{1000} = 72\,\text{dB}.$$

As a first approach σ is taken equal to 1. A full calculation delivers the following results:

frequency	Ln	frequency	Ln	frequency	Ln
	terts		octave		EN
50	60,9	63	67,5	63	65
63	62,3	125	73,1	125	73
80	64,2	250	74,8	250	78
100	66,9	500	76,1	500	78
125	68,6	1000	77,1	1000	78
160	69,1	2000	78,2	2000	78
200	69,6	4000	79,3	4000	76
250	70,0				
315	70,5	**Lnw**	**80**	**Lnw**	**79**
400	71,0	**CI**	**-12**	**CI**	**-10**
500	71,4				
630	71,7				
800	72,0				
1000	72,3				
1250	72,7				
1600	73,1				
2000	73,4				
2500	73,8				
3150	74,1				
4000	74,5				
5000	74,8				
Lnw	**80**				
CI	**-12**				

A close approximation of the EN-results is obtained. The procedure in the annex is not exhaustively documented and there is also no doubt that empirical corrections should be applied at the higher frequencies in order to adapt for a non perfect Dirac impact or "local spring-like interaction".

Selection of default material data list

After a search in own data, literature and some consultation within the research team a list of data was prepared.

Materiaal	Duits	Engels	Frans	Soortelijke [kg/m3]	Golfvoort- [m/s]	Demping [-]
Staal	Stahl	Steel	Acier	7800	5050	0.01
Lood	Blei	Lead	Plomb	11300	1250	0,02
Gewapend beton	Stahlbeton	Reinforced	Béton armé	2400	3700	0,015
Betonblokken	Betonstein	Concrete bricks	Blocs de béton	1700	3500	0,015
Gasbeton	Porenbeton	Aerated concrete	Béton cellulaire	650	1700	0,015
Licht beton	Leichtbeton	Lightweight concrete	Béton léger	900	2000	0,015
Kalkzandsteen metselwerk in blokken	Kalksandstein mauerwerk	Sandlimestone brickwork	Maçonnerie traditionnelle en silicocalcaire	1300	3000	0,015
Kalkzandsteen	Kalksandstein	Sandlimestone	Eléments en	1800	3000	0,015
Licht	Lochsteinmauerw	Very lightweight	Maconnerie en	800	2500	0,015
Normaal	Lochsteinmauerw	Normal	Maconnerie en	900	2500	0,015
Zwaarder	Lochsteinmauerw	Heavier	Maconnerie en	1100	2500	0,015
Vol metselwerk	Vollziegelmauerw	Heavy brickwork	Maconnerie en	1700	2500	0,015
Hout licht	Holz leicht	Wood light	Bois léger	500	2500	0,03
Hout zwaar	Holz schwer	Wood heavy	Bois lourd	1000	2500	0,03
Gipsplaten	Gipskartonplatten	Gypsumboard	Plaque de plâtre	950	1800	0,03
Vezelversterkte	Gipsfaserplatten	Fiber reinforced	Plaque de plâtre	1200	**2000**	**0,02**
Gipsblokken licht	Gipsbauplatten	Gypsum blocks	Blocs de plâtre	800	1900	0,01
Gipsblokken	Gipsbauplatten	Gypsum blocks	Blocs de plâtre	1200	1800	0,01
Glas	Glas	Glass	Ver	2500	5000	0,01

All default materials where calculated for series of relevant thicknesses. Plastering on one side was considered equivalent to 1 cm extra thickness for stony material. In global 356 air-borne sound insulation results were produced. They include octave, third octave results and all relevant weighting indices. The next graph shows an overview of the single number ratings which resulted.

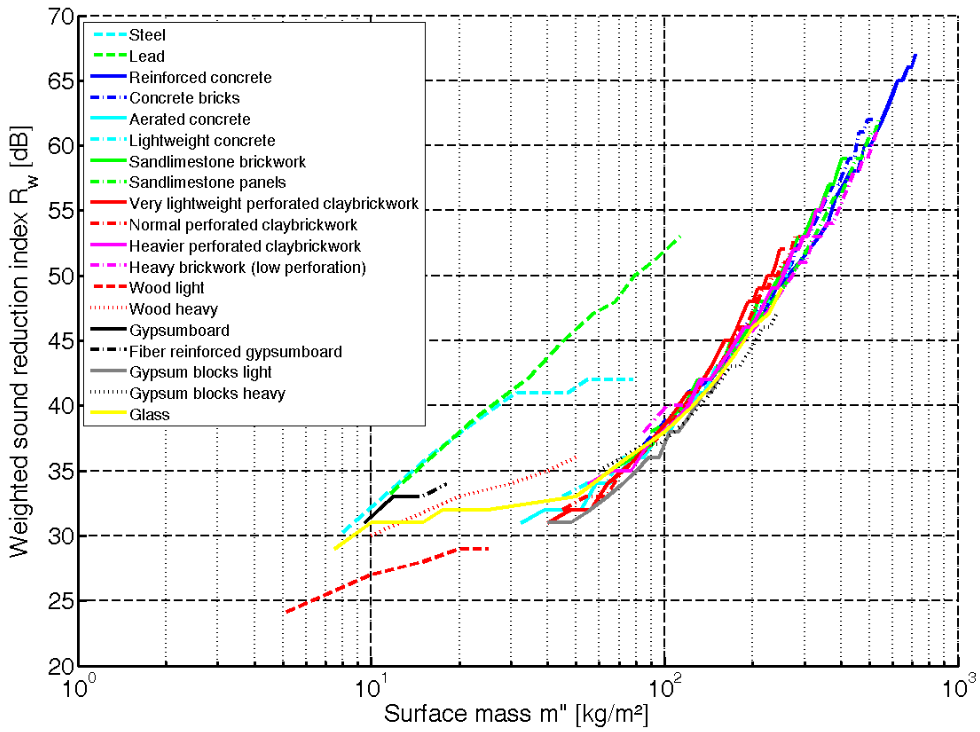


Figure 16: R_w values as derived from the third octave predictions in the function of the surface mass

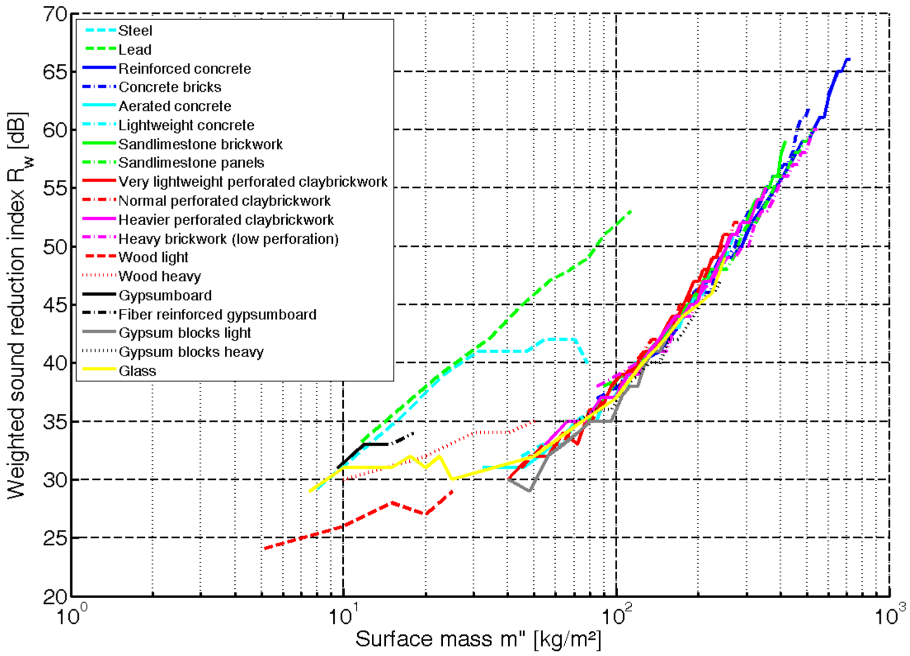


Figure 17: R_w values as derived from the octave predictions

For impact sound insulation the significance of monolithic constructions is less because for obtaining reasonable quality level the application of a multilayer is the standard. For this reason the results are derived for reinforced concrete only, mainly as a reference.

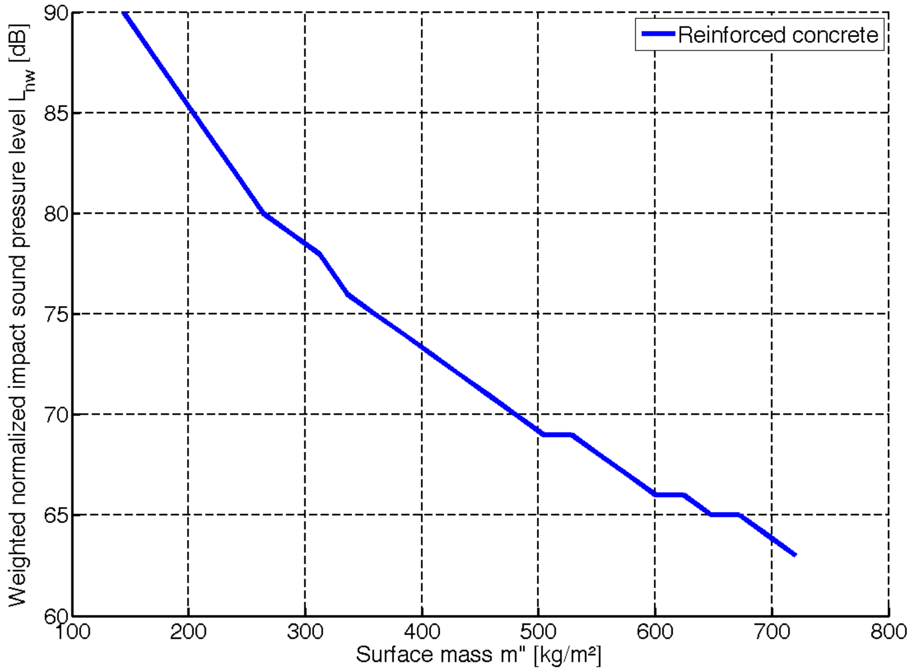


Figure 18: L_{nw} values as derived from the third octave predictions

From these calculations 35 spectra where added to the database.

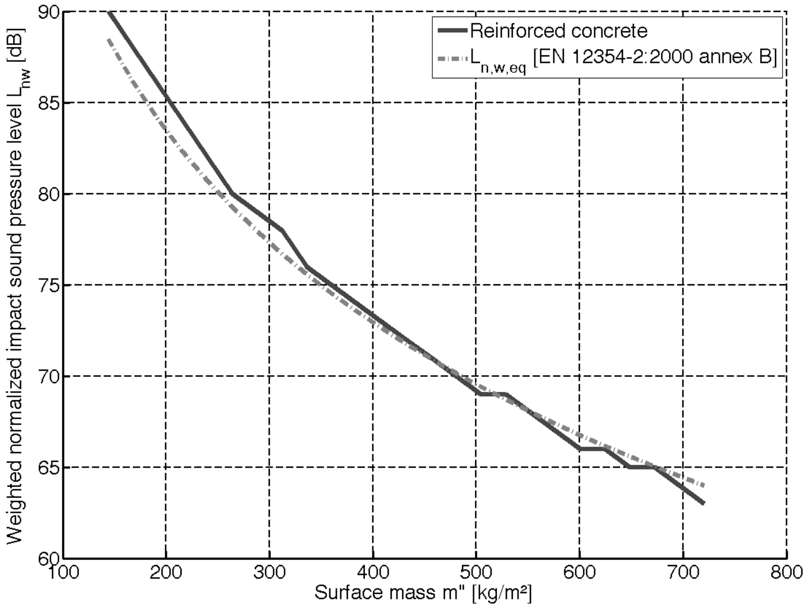


Figure 19: Comparison of calculated results to the approximation as suggested in (NBN EN ISO 12354-2, 2000). $L_{nw,eq}$ refers to (NBN EN ISO 717-2, 1996) and to the bare concrete floors

Conclusions

The fundamental characteristics of sound insulation quantities have been shortly introduced. The nature of the quantities introduces a lot of uncertainties. No specific sound insulation material property exists. This means that the quality is related to more than the mechanical material properties themselves. A rather large spread on the reported laboratory results is a reality which not only reflects real quality differences. This is a good reason for the development of a series of representative default values as input to the Tiatab databank.

The predictions of the monolithic partitions properties: airborne sound insulation and impact sound insulation are based on the relevant formula as given in the European procedures. In this paper the related formula are commented. After a search in own data, literature and some consultation within the research team a list of data was prepared. Comparisons to other procedures/programs are shortly discussed. In global some 400 extra airborne and in fact sound insulation spectra were produced as input to the databank.

5. C. PROGNOSIS OF DOUBLE WALLS? POSSIBILITIES AND LIMITATIONS

Introduction

Double walls and multilayered structures are often encountered in buildings. Double glazing and cavity walls are typically used because of their superior performance regarding thermal insulation. Lightweight sandwich roof panels are commonly used in buildings because of the ease and speed of installing and the potential for very high and reliable thermal insulation. Double wall constructions are also introduced to achieve a better sound insulation with a minimum of weight. Examples are double gypsum board walls with a timber or steel frame construction and lowered ceilings. A simple and cheap method to increase the transmission loss of an existing wall is to cover them with a second, additional lining.

The European standards EN 12354 "*Building acoustics: estimation of acoustic performance in buildings from the performance of elements*" give a framework for building acoustical calculations. To get reliable results, the knowledge of the acoustical properties of the different building elements is important. In essence, a double wall consists of two plates separated from each other by an air layer. The large variation in double wall structures however makes it very difficult to take into account all parameters determining the sound transmission loss. For double walls, next to the material properties of the two plates and the thickness of the air layer, a number of other parameters are important. The air layer can be filled with an absorbing material, which significantly increases sound transmission loss. Structural connections like studs or cavity ties can significantly influence the sound transmission. One also has to take into account the properties of the studs: rigid connections like wooden studs behave differently compared to flexible steel studs. Furthermore, practical details like the attachment method of the plates to the studs can influence the sound insulation characteristics.

Chapter 5.C. investigates the possibilities and limitations of several types of models for double walls and multilayered structures described in literature. Comparison of the models with each other and with experiments shows that the accuracy of the models is often insufficient. Theoretical models are useful for parametric studies and product development. However, datasets based on measurements of double walls are needed as input for accurate estimations of the global acoustic performance of buildings.

Theoretical models

To predict the vibro-acoustic behaviour of double walls, several types of models are used in literature. These models can be classified in three categories: analytical models, deterministic models and statistical models, see Figure 20. Each type of model has its specific assumptions and therefore its limitations. These will be discussed in this section.

Analytical models

The oldest and most simple models used for single and double walls are analytical models. All analytical models assume infinite layers. This makes them computationally efficient. Examples are the impedance method, used by Beranek and Work (Beranek & Work, 1949) and Mulholland *et al.* (Mulholland, Parbrook, & Cummings, 1967), and the progressive-wave method, introduced by London already in 1950 (London, 1950) and further elaborated by Fahy (Fahy, 1985).

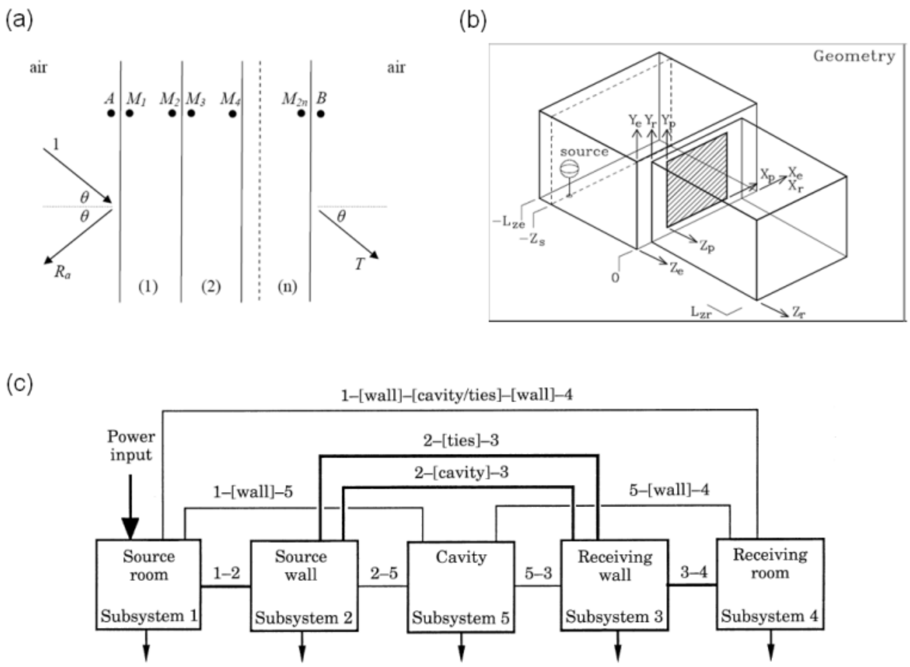


Figure 20: Sound transmission loss models (a) Analytical models (b) Deterministic models (c) Statistical models

These analytical methods give good insight in the general behaviour of double wall systems, which is schematically shown in Figure 20. The most important parameter of a double wall is its mass-air-mass-resonance frequency f_0. Below this frequency, the double wall behaves as a single wall. Around f_0, the curve shows a typical resonance dip. The positive double-wall effect is visible above f_0. In this frequency range, the sound transmission loss of a double wall is significantly better than that of a single wall with the same surface mass. At higher frequencies, the sound transmission loss is restricted by resonances in the air cavity. It is important to damp these resonances by placing absorbent material in the air cavity.

At the Laboratory of Acoustics and Thermal Physics of the K.U.Leuven, a transfer matrix method was developed (Lauriks, 1990) to calculate the sound transmission through multilayered structures. The configuration of this method is shown in Figure 20(a). The plane wave propagation through a number of layers is described by means of transfer and interface matrices. A transfer matrix describes the wave propagation through each layer. The continuity conditions between each layer are described by interface matrices. A double wall is modeled as a three-layer system: a plate, an air layer and a plate. The advantage of the transfer matrix method is the possibility to include more layers. Cavity absorption can be readily taken into account by modeling an extra (poro-elastic or equivalent fluid) layer in the cavity.

One of the main limitations of the analytical models is the assumption of infinite layers. As a result, the effects of the finite dimensions, like the modal behaviour and the diffraction effects, are not taken into account. Secondly, analytical models calculate the transmission coefficient for a plane wave excitation at one angle of incidence θ. In reality, a structure is of course excited by more than one acoustic wave from different directions. Therefore, one needs to calculate a mean sound transmission loss. The assumptions made for the incident sound field in this averaging process can strongly influence the global sound transmission loss. Most ideally, a diffuse field is assumed. To get better agreement with measurement results, a maximum angle of incidence (between 70° and 85°) is often taken into account.

Other researchers have proposed a Gaussian distribution of incident energy (Kang, Ih, Kim, & Kim, 2000). Especially for double walls, the choice is important as the sound transmission is strongly dependent on the angle of incidence.

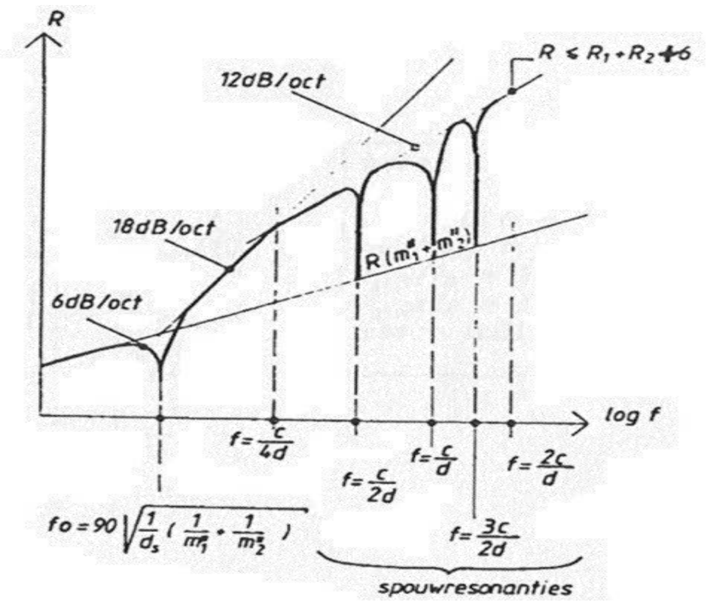


Figure 21: Sound insulation of double walls: classical infinite wall theory (source: (Vemeir, 1999))

Deterministic models

In reality, the sound transmission loss as measured in the laboratory or in situ is not a property of the structure alone. The measured sound transmission loss is dependent on the situation. The geometry, the room dimensions, the plate dimensions and the position of the structure in the common wall all influence sound transmission. Sound transmission loss is determined in function of the measured sound pressure level difference between two rooms. Especially in the lower frequency range, this difference is determined by the interaction between room and plate modes.

Finite element models (Panneton & Atalla, 1996) and modal models (Gagliardini, Roland, & Guyader, 1991) incorporate the influence of these geometric parameters. The finite dimensions of rooms and structure are taken into account, see Figure 20(b). At the Laboratory of Building Acoustics of the K.U.Leuven, a modal model was developed for single walls (Osipov, Mees, & Vermeir, 1997a) and extended for double walls and multilayered structures (Dijckmans, Vermeir, & Lauriks, 2009). For double walls, the influence of the finite dimensions can be very significantly. As an example, the sound transmission loss of a double glazing structure (6-12-8 mm) is calculated with an analytical model and a modal model. The results are plotted in Figure 22. Below the coincidence dip (1600-2000 Hz) the influence of the finite dimensions is very large.

Generally, deterministic models give better prediction results compared with analytical models, because reality is modelled in a more detailed way. They can take into account the finite dimensions of the rooms and the double wall. Moreover, mechanical links like studs can be incorporated in a detailed way in finite element models. However, the computation time of the models is high (Osipov, Mees, & Vermeir, 1997b).

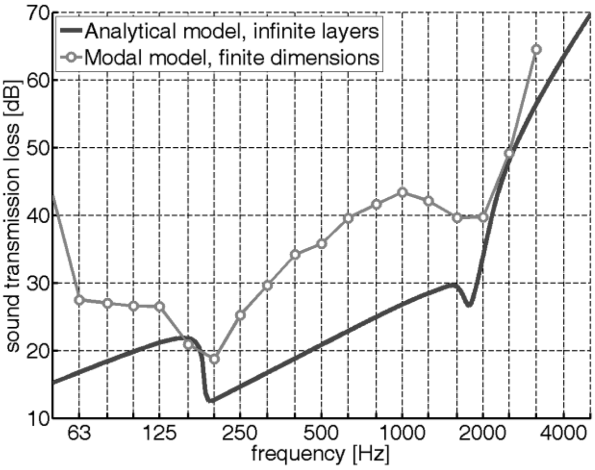


Figure 22: Sound transmission loss of double glazing: influence of finite dimensions

Statistical models

A third category consists of the statistical models. Statistical Energy Analysis (SEA) is a method where the vibro-acoustic problem under investigation is modelled as a number of subsystems. Assuming a high modal density in each subsystem, the vibro-acoustic behaviour of a subsystem is determined by its mean energy level only. SEA calculates the energy levels by solving the energy balances between the several subsystems.

Price and Crocker (Price & Crocker, 1970) made an SEA-model for a double wall without mechanical connections. Source and receiving room, the two plates and the cavity are modelled as subsystems, see Figure 20(c). Davy (Davy, 2010) included the effects of rigid or flexible studs. Craik and Wilson (Craik & Wilson, 1995) incorporated the structure-borne sound transmission through cavity ties in a masonry cavity wall.

The methodology of SEA is quite simple, making the incorporation of flanking transmission or stud-borne transmission straightforward. However, the important parameters in the models – internal damping and coupling factors – are difficult to determine for double walls. Furthermore, the assumption of high modal density is not valid in the low- and mid-frequency range.

Experimental validation

Hongisto (Hongisto, 2006) made a study on the performance of predictions for double walls' airborne sound insulation. He investigated 17 analytical and statistical models for double walls by comparing them among each other and against experimental results. Four categories of double walls were investigated: without studs and cavity absorbent, without studs and with absorbent, rigid studs with absorbent, and flexible studs with absorbent. Figure 23 shows some validation data from (Hongisto, 2006). First, it can be seen that the variation between the different models is very large, even for the simplest type of double walls without studs and cavity absorbent. The average prediction errors for R_w are as high as 15 dB. Secondly, it can be seen that with increasing complexity of the structure, the number of models available is limited. For example, only two prediction models are able to predict sound transmission through double walls with flexible studs and cavity absorbent.

The conclusions of Hongisto read: *“The average prediction errors for individual frequencies were as high as 20 dB (R_w: 15 dB) for the best models. None of the models was sufficiently accurate in all four categories. There is an obvious need to develop a new model, which can be reliably applied to arbitrary double and multilayer walls. […] Only few models could predict the sound insulation with acceptable accuracy, but none of them was capable of predicting the whole spread of commercial wall types consisting of varying layers of (flexible) studs, absorbents, cavities and partition panels.”*

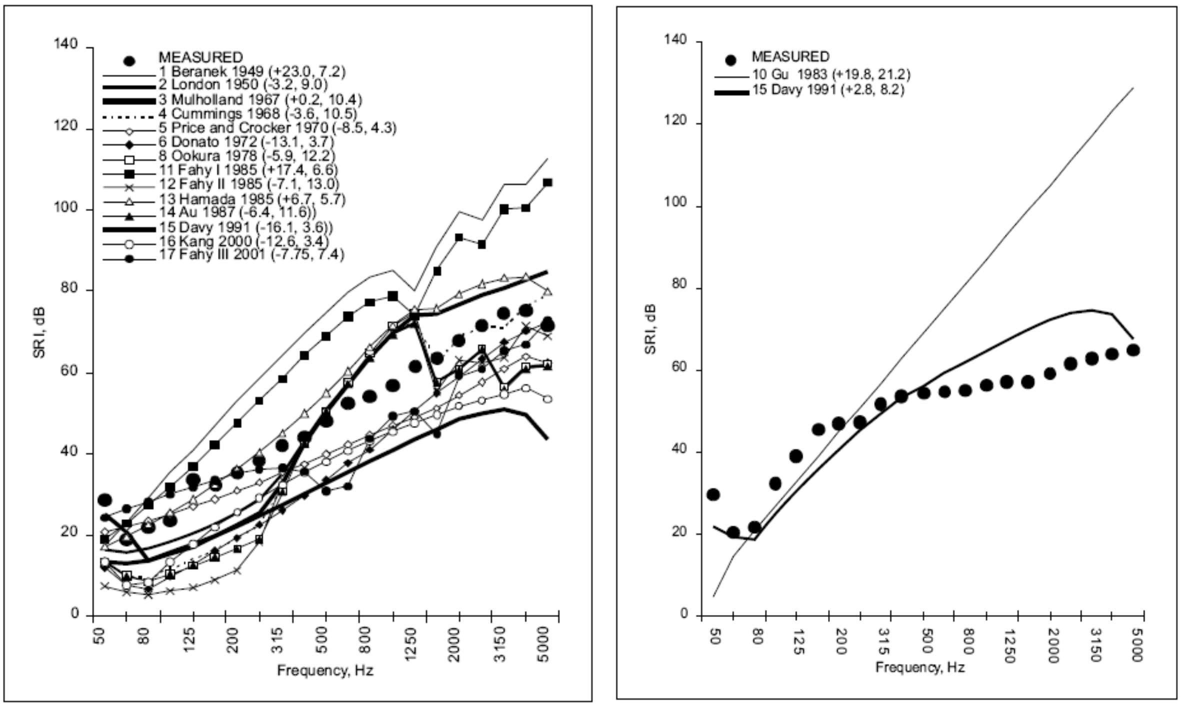


Figure 23: Comparison of existing models with experiment: double walls (a) without studs and cavity absorption (b) flexible studs with cavity absorption (source: (Hongisto, 2006))

Conclusions

A whole range of models have been developed in literature to predict the airborne sound insulation of double walls and multilayered structures. These include analytical, deterministic and statistical models. A lot of parameters have to be taken into account. Next to material properties of the plates, the studs, cavity absorption, geometry,… determine the global sound insulation. Furthermore, practical details like the attachment method of the plates to the studs can influence the sound insulation characteristics. As a result, each model makes some assumptions and simplifies reality. In this way, these models can be useful for the scientific analysis of certain types of constructions or product development. However, it should be clear from the extensive study from Hongisto that no superior model exists for double walls and multilayered structures. No model exists which is capable of predicting sound insulation of all types of double and multilayered walls with sufficient accuracy. In the author’s opinion, the complexity of the problem does not allow to develop a generally applicable prediction model. Therefore, for double walls and multilayered structures, acoustic data must always be supported by well documented experimental results.

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6. Acoustic and thermal structural concepts for terraced housing and apartments with decoupled double party cavity walls

6. A. INTRODUCTION

A range of structural building concepts exist which enable the criteria for normal and enhanced acoustic comfort to be satisfied for terraced houses and apartments. The regulations governing the thermal performance EPR are also a factor within these construction concepts. These new regulations require that thermal insulation be installed between two apartments. In practice, this means that a double wall must be installed with the thermal insulation in the cavity between the two leaves. In this text, only solutions are considered in which the party wall already consists of decoupled double supporting walls equipped with thermal insulation in the cavity. Other structural building concepts (for example involving lining walls) are the subject of the more detailed reporting. The different structural building concepts are described in reference sheets at the end of the document. The main document provides a more detailed description of the design and execution issues and explains the principles behind the acoustic performance obtained by means of a certain design.

At the end of January 2008, the "*NBN S01-400-1: Acoustic criteria for dwellings*" standard came into force. The performance requirements formulated in the standard are considered to be good working practice and are applicable to all residential buildings on Belgian territory for which planning permission was submitted after the publication date of the standard. The standard sets out requirements for airborne and impact sound insulation and for the sound insulation of the outside wall, and also places limits upon the noise emanating from buildings services.

The formulated requirements apply to the finished structure, but also serve as the terms of reference for the production of a design. They are thus relevant during conceptual and detail design work and to the methods of implementation.

Two quality levels are specified in the standard:

- ***Normal acoustic comfort (abbreviated "NAC" in this document)****: the minimum quality level, associated with requirements concerning the acoustic comfort which are intended to assure the satisfaction of a clear majority of users. This is set at over 70% of users for airborne and impact sound insulation under normal noise exposure conditions.*
- ***Enhanced acoustic comfort (abbreviated "EAC" in this document)****: this is the highest acoustic quality level in the above standard; the associated requirements have as their objective the attainment of an enhanced level of acoustic comfort for a specified acoustic property. This applies to the external wall insulation, the sound insulation between dwellings, the impact sound insulation, and the noise emanating from buildings services. The percentage of satisfied residents is set at over 90% of users for airborne and impact sound insulation under normal noise exposure conditions. The requirements for enhanced acoustic comfort apply when they are*

specified by the parties behind a construction project (the client, purchaser, etc.) or when they have been assured to future residents by the seller or landlord.

The requirements concerning the airborne and impact sound insulation between apartments specified in the new Belgian standard governing residential buildings, NBN S01-400-1, are reproduced here (unofficial translation):

Source room outside the dwelling	Receiving room inside the dwelling	Normal acoustic comfort (NAC)	Enhanced acoustic comfort (EAC)
All rooms	All rooms with the exception of buildings services rooms and entrance halls	Airborne sound insulation: $D_{nT,w} \geq$ 54 dB Impact sound insulation: $L'_{nT,w} \leq$ 58 dB	Airborne sound insulation: $D_{nT,w} \geq$ 58 dB Impact sound insulation: $L'_{nT,w} \leq$ 50 dB
Source room inside the dwelling	**Receiving room inside the dwelling**	**Normal acoustic comfort (NAC)**	**Enhanced acoustic comfort (EAC)**
Bedroom, kitchen, living-room and bathroom (not en-suite)	Bedroom, study	Airborne sound insulation: $D_{nT,w} \geq$ 35 dB Impact sound insulation: No requirements	Airborne sound insulation: $D_{nT,w} \geq$ 43 dB Impact sound insulation: $L'_{nT,w} \leq$ 58 dB
Exceptions			
1) When the adjacent property is not residential, specific requirements apply in consideration of the possible noise exposure in the adjacent rooms (refer to NBN S01-400-1:2008 for details). 2) For impact sound, the requirement for normal acoustic comfort is higher by 4 dB in situations in which the receiving room is a bedroom and the source room in the other dwelling is not a bedroom. 3) During assessment of these values on the finished structure, it is assumed that a result is still considered to be compliant if 2 dB less than the specified requirement. This margin is due to uncertainties in the prognosis and to limits in the accuracy of the measurement methods.			

Table 3: Requirements for airborne and impact sound insulation in apartments

The presence of neighbours above and below renders the issue of acoustics in apartments somewhat more difficult than in terraced houses: additional requirements apply in this case in the vertical, horizontal and even diagonal directions. The issue of impact sound insulation is also much more relevant in apartments located one above the other, and limitation of the noise emanating from buildings services requires much closer attention. The likelihood of errors, resulting in a poor level of acoustic comfort, is therefore much greater than in terraced houses. At the same time, the residents of an apartment have somewhat lower expectations regarding the acoustic comfort than do the residents of terraced houses. The requirements concerning the airborne sound insulation between two apartments are thus somewhat lower than between terraced houses. It is therefore more difficult, albeit not impossible, to achieve sound insulation between apartments that is as good as that between terraced houses.

Source room outside the dwelling	Receiving room inside the dwelling	Normal acoustic comfort (NAC)	Enhanced acoustic comfort (EAC)
All rooms	All rooms with the exception of buildings services rooms and entrance halls	Airborne sound insulation: $D_{nT,w} \geq 58$ dB Impact sound insulation: $L'_{nT,w} \leq 58$ dB	Airborne sound insulation: $D_{nT,w} \geq 62$ dB Impact sound insulation: $L'_{nT,w} \leq 50$ dB
Source room inside the dwelling	Receiving room inside the dwelling	Normal acoustic comfort (NAC)	Enhanced acoustic comfort (EAC)
Bedroom, kitchen, living-room and bathroom (not en-suite)	Bedroom, study	Airborne sound insulation: $D_{nT,w} \geq 35$ dB Impact sound insulation: No requirements	Airborne sound insulation: $D_{nT,w} \geq 43$ dB Impact sound insulation: $L'_{nT,w} \leq 58$ dB
Exceptions: Identical as in Table 3			

Table 4: Requirements concerning the airborne and impact sound insulation in new terraced houses (dwellings for which the application for planning permission was made after 28 January 2008, which are normally intended for habitation by a single family, and which have partition structures on one or two sides separating them from other buildings)

The solutions are divided into 6 "families" of structural building concepts, and are described in detail at the end of this document:

- ***Structural building concept 1****: Structures with DISCONTINUOUS FLOOR SLABS and a party wall in the form of HEAVY CAVITY WALLS (sand-lime brick, heavy hollow concrete blocks) WITHOUT anchors or other structural ties;*

- ***Structural building concept 2:*** *Structures with DISCONTINUOUS FLOOR SLABS and a party wall in the form of MIDDLEWEIGHT CAVITY WALLS (hollow bricks, hollow concrete blocks) WITHOUT anchors or other structural ties;*

- ***Structural building concept 3:*** *Structures with DISCONTINUOUS FLOOR SLABS, RESILIENT STRIPS and a party wall in the form of MIDDLEWEIGHT CAVITY WALLS (hollow bricks, hollow concrete blocks) WITHOUT anchors or other structural ties;*

- ***Structural building concept 4:*** *Apartments (acoustically not applicable to terraced houses) with CONTINUOUS FLOOR SLABS and a party wall in the form of DOUBLE HEAVY CAVITY WALLS (sand-lime brick, heavy hollow concrete blocks);*

- ***Structural building concept 5:*** *Structures with CONTINUOUS FLOOR SLABS, RESILIENT STRIPS and a party wall in the form of MIDDLEWEIGHT CAVITY WALLS (hollow bricks, hollow concrete blocks) WITHOUT anchors or other structural ties;*

- ***Structural building concept 6:*** *Particular industrial solution from a manufacturer of hollow core slabs.*

6. B. AIRBORNE SOUND TRANSMISSION BETWEEN TERRACED HOUSES AND BETWEEN ADJACENT APARTMENTS ON THE SAME LEVEL

Direct airborne sound transmission (Figure 28) between terraced houses and between adjacent apartments on the same level

The direct sound transmission is shown in Figure 28 by the "Dd" arrow, and represents the sound transmission through the party wall. The insulation against this direct sound transmission is heavily dependent upon the coupling between the two leaves:

- *Where the coupling between the two party wall leaves is significant (such as when the two walls are linked by anchors, when mortar bridges exist between the two party wall leaves, when the floor slabs are continuous, thus linking the two leaves of a party wall, etc.), the system as a whole behaves acoustically almost in the same way as a single wall. The sound insulation is then determined largely by the common mass per unit area of the two party wall leaves: the heavier they are, the better the direct sound insulation. This situation is present in* ***structural building concept 4****, in which the two party wall leaves are coupled to each other at the bottom and top by the continuous floor slab: only where the leaves are heavy (such as 2 x 15 cm sand-lime brick or equally heavy concrete blocks) is the direct sound insulation sufficient to attain normal acoustic comfort.*

- *Where no coupling exists between the party wall leaves, the system acts acoustically as a highly efficient double-wall structure. The direct sound insulation in this case is appreciably higher than in the previous case. Provided the other flanking transmissions and/or leakage sound is limited, enhanced acoustic comfort is possible.* ***Structural building concepts 1, 2, 3 and 6*** *follow this principle: they consist of party wall leaves without anchors or other ties; the floor slabs are interrupted at the cavity; all other possibilities of coupling are avoided (no continuous inner cavity wall leaf), etc. Only at the foundation level is coupling possible. The influence of this coupling can however be limited by observance of the building codes concerning the foundation and the bottom floor slab (see 6.D.). In* ***building structure concept 5****, too, the wall acts acoustically as a decoupled double-wall structure despite the continuous floor slabs. The resilient layers above and below the party wall leaves where they meet the supporting floors adequately decouple the two leaves such that the double-wall effect is largely retained. In order for this to be achieved, the following conditions must be met: 1) no (or as few as possible) mortar bridges should exist which connect the floor slab and the wall rigidly across the resilient joint; 2) the edge strips for the floating floor must be installed prior to the levelling screed (otherwise, a rigid coupling is produced via the levelling screed); 3) the plastering in the transition at the corner between load-bearing wall and a ceiling slab must be interrupted up to the elastic joint. The break may be filled at a later stage with a permanently elastic product.*

Figure 24: Improved acoustic technology for middleweight structures (structural building concepts 3 and 5): by proper installation of a vibration-damping strip (black strip in the photograph) beneath all walls, the sound insulation between apartments situated one above the other can be increased appreciably. Any rigid contact bridge between a brick wall and the structure beneath it must be avoided. The edge impact sound insulation (in this case the grey-white PE foam) must therefore be installed right up to the floor slab, and BEFORE the levelling screed is installed over the pipes.

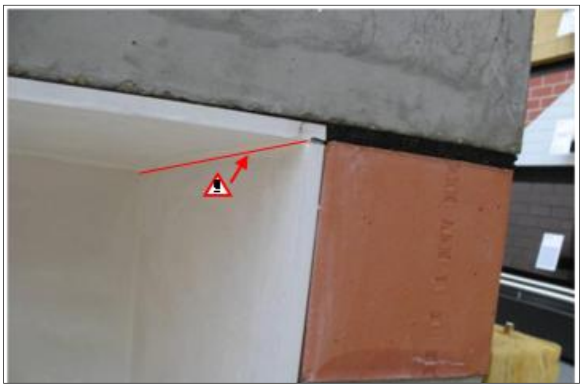


Figure 25: Structural building concept 5: using a cutter, cut the plastering at the joint between the slab and the wall through into the resilient layer, in order for vibration coupling to be avoided here as well.

Figure 26: Very high sound insulation levels (R_w > 65 dB) can be obtained by means of a double wall of sand-lime brick (m”>250 kg/m²) provided no rigid contact exists between the party wall leaves. Serious errors may however be made at the level of the floor supports. With coupling as shown by this figure, the sound insulation can easily drop by 10 dB or more.

Figure 27: Avoid contact bridges at the bearing points of the hollow core slabs: errors may be made here particularly during pouring of the topping. Left: The installation of metal edge profiles at the level of the cavity serving as a casing for pouring of the topping is a good solution if executed carefully. The figure further shows a risk of the concrete mortar penetrating the cavity in the gaps between the mineral wool and the edge profiles. A seal must also be provided here between two adjacent edge profiles. Right: Alternative solution involving a combination of rigid PU plate/mineral wool/rigid PU plate for pouring of the concrete topping.

Flanking airborne sound transmission (Figure 28) between terraced houses and between adjacent apartments on the same level

What is "flanking airborne sound transmission"?

In Figure 28, the two party wall leaves are coupled to each other so tightly that they act acoustically as a single wall. Figure 28 shows the airborne sound transmission paths to the adjacent apartment for this situation, which are visible on the cross-section. In order to describe the various paths unambiguously, the names of the walls on the source side are denoted by an upper-case letter, those on the receiving side by a lower-case letter (consistent with the international agreement in accordance with the EN 12354 series of standards). Party walls (and also floors for transmission in the vertical direction, see below) are denoted by the letters “D” and “d” (according to whether they are on the source or receiving side), flanking walls by the letters “F” and “f”. In addition to the direct transmission path of the sound through the partition wall “Dd” described above, 3 flanking paths can be distinguished in each junction (cross-section of the end wall with the separating party wall):

- *Ff” represents the transmission path from the flanking end wall “F” of the room on the source side to the flanking wall “f” of the room on the receiving side. This transmission occurs when the sound causes the wall of the room on the source side to vibrate; this wall then passes its vibration on to the wall of the room on the receiving side, where it is retransmitted in the form of sound.*

- *Similarly, “Fd” represents the vibration transmission path for the flanking wall “F” of the room on the source side to the party wall “d” of the room on the receiving side.*

- *“Df” represents the vibration transmission path for the party wall “D” of the room on the source side to the wall “f” of the room on the receiving side.*

A room that is constrained by four walls that continue through to the next room thus has no fewer than 4 x 3 flanking paths and one direct sound transmission path, namely “Dd”.

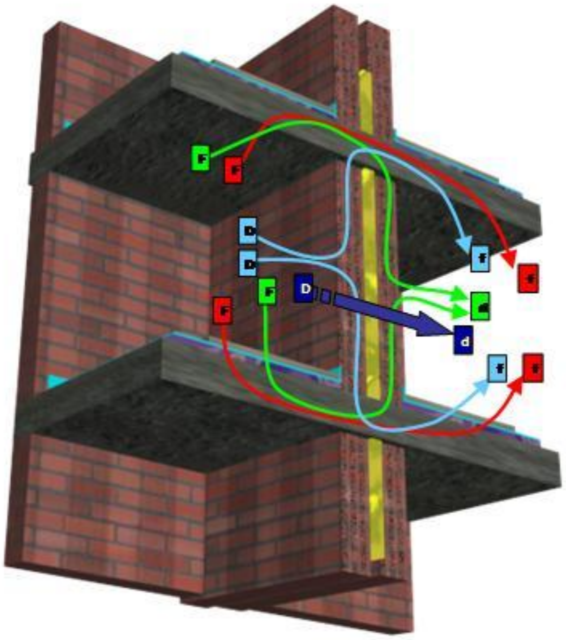


Figure 28: The various airborne sound transmission paths to the adjacent apartment

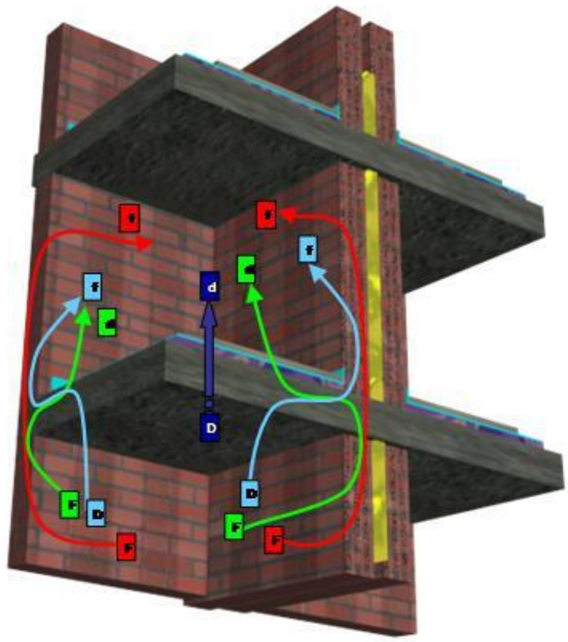


Figure 29: The various airborne sound transmission paths to the apartment above

<u>How can the “flanking airborne sound transmission” be limited?</u>

The flanking sound insulation for a given path (e.g.“Ff”) increases with increasing mass per unit area of the wall on the source side (of the flanking wall F), with increasing mass per unit area of the wall on the receiving side (the wall f), and with increasing coupling damping K_{Ff}

for this transmission path at the junction (intersection) with the supporting floor. The coupling damping K_{Ff} is also associated with a ratio of mass to unit area, but further consideration of this aspect lies outside the scope of this document. We refer in this context to the article "*Akoestische isolatie tussen ruimten - Isolation acoustique entre locaux, WTCB-magazine - Revue CSTC, Spring 2001*".

This flanking sound insulation can be improved further by the fitting of lining walls over the wall on the source and/or receiving sides. A more drastic measure is the installation of a proper vibration break (anchorless cavity wall construction), as applied in structural building concepts 1 and 2. This results in all flanking sound transmission between apartments in the horizontal plane being avoided. The EN 12 354-1 standard contains methods for prognostic calculation of the flanking sound transmission.

<u>How is the flanking sound transmission to the adjacent terraced house or apartment addressed in the various structural building concepts?</u>

- *In **structural building concept 4**, only the floor slabs are continuous between two apartments; all walls are interrupted by the cavity in the party wall. The flanking sound transmission via the floor is strongly attenuated by the floating floor construction in the two apartments or terraced houses, which has the same effect against the flanking transmission of sound as a lining wall. By the selection of an adequately heavy floor slab and heavy party wall leaves, the flanking sound transmissions Ff, Df and Fd are adequately attenuated. Normal acoustic comfort can be attained by means of this concept.*

- *Construction of the cavity wall without ties and the use of discontinuous floor slabs in **structural building concepts 1, 2, 3 and 6** prevents flanking sound transmission between adjacent apartments (except at the foundation level where it can be considerably decreased by taking adequate measures, see chapter foundations).*

- *The resilient layers in **building concept 5** at the transition to the floor slabs above and below the load-bearing walls break the greater part of the flanking airborne sound transmission paths to the adjacent apartment. The transmission path Ff via the floor slab is also negligible, owing to screening by the floating floors. Only the path Ff via the ceiling slab remains; this can be limited by use either of a heavier floor slab, or of suspended ceilings (more information can be found in the extensive research documents and the publications on our website www.normen.be).*

6. C. AIRBORNE SOUND TRANSMISSION BETWEEN APARTMENTS SITUATED ONE ABOVE THE OTHER

Direct airborne sound transmission between apartments situated one above the other

The installation of floating floors is (indirectly) mandatory in newly build apartments in Belgium. Direct sound transmission in **structural building concepts 1 to 5** thus occurs through a “double acoustic wall” consisting of the supporting floor (with levelling screed), a spring (the resilient intermediate layer) and the floating floor.

The direct airborne sound insulation improves with increasing weight of the supporting floor and increasing resilience of the resilient intermediate layer. The resilient properties of the resilient intermediate layer are expressed by the quantity ΔL_w (the improvement in impact sound insulation), a higher value leading to a superior acoustic result. (See also "*Isoler les planchers massifs contre les bruits de choc*, *M. Van Damme, Revue CSTC 2010")*

Structural building concept 6 (see the end of this chapter 6) represents an integral solution from a particular company. Two hollow core slabs located one above the other are coupled by a resilient strip. Here too, the system acts as an acoustically ideal double wall, with very high resulting insulation against airborne and impact sound.

Flanking airborne sound transmission (Figure 29) between apartments situated one above the other

In the particular industrial solution in accordance with **structural building concept 6**, flanking sound transmission to the apartment above is negligible.

For the other **structural building concepts, 1 to 5**, we shall now consider the situation for sound transmission from an apartment to the apartment located above it. The principles are completely analogous for the reverse direction. Here too, 3 flanking sound transmission paths are possible per junction (intersection between the floor slab and vertical brickwork).

In **all structural building concepts 1 to 5**, sound transmission from an apartment to the apartment above it via path **Fd** is negligible: the floating floor acts as an acoustic lining wall. The floating floor is therefore not only extremely important in order for good impact sound insulation to be assured, but is equally essential for airborne sound insulation.

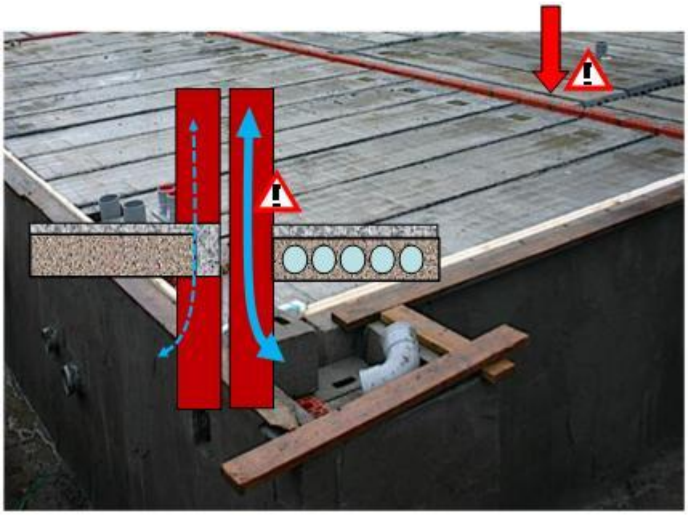


Figure 30: Hollow core slabs and concrete slabs must bear upon all supporting walls which continue through to other storeys. This may involve supporting on four sides. If this is not assured, significant sound transmission between storeys may occur through the wall.

The sound transmission for the paths **Df and Fd** is determined by the masses per unit area of the party wall leaves and the ceiling slab (the heavier, the better) and the coupling damping in the junction.

In order for the coupling damping to be assured for path Ff, the floor slabs must also bear properly on all supporting walls. If this is not assured, the flanking sound transmission Ff becomes highly significant and the acoustic requirements will not be met.

- *Structural building concepts with heavy party wall leaves (**structural building concepts 1 and 4**) and floor slabs thus score very highly.*
- *Should lighter designs be used, the flanking transmissions Df and Ff may give rise to excessively weak sound insulation. This shortcoming can be corrected by the application of lining walls (not discussed in this text). The use of very heavy supporting floors (>650 kg/m²) also represents a solution (**structural building concept 2**): the flanking sound insulation for the paths Ff and Df increases at a higher mean mass per unit area and/or with superior coupling damping (the higher mass per unit area of the floor slab also leads to a perceptible improvement in the coupling damping, particularly for path Ff).*
- *A space-saving and less expensive alternative is the installation of resilient strips just above the supporting floor slab beneath all supporting walls. This principle is applied in **structural building concept 3** (and also in **structural building concept 5**, in which a resilient layer is installed above and beneath the floor slab).*

6. D. BUILDING CODES APPLICABLE TO THE FOUNDATIONS

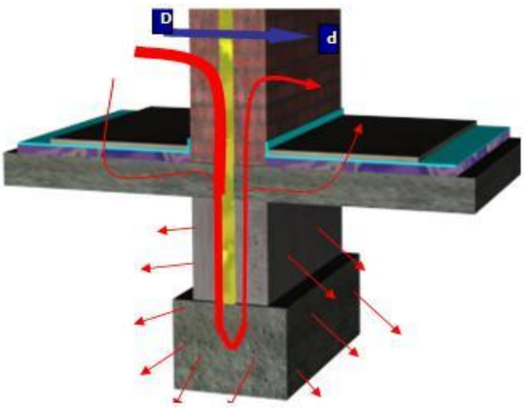


Figure 31: Structural sound transmission through the foundations in structural building concepts based upon the construction principle involving cavity walls without ties

In order for the best possible sound insulation to be attained with a double-wall system, acoustic theory requires any structural contact with walls with high bending stiffness – such as stone structures – to be avoided. For construction reasons, however, a significant coupling at foundation level is indispensable.

This structural transmission path, indicated by the red arrows in Figure 31, can however be strongly attenuated by judicious design and implementation, with the result that outstanding sound insulation can still be assured.

Where a crawl space/cellar or deepened strip foundation is present, the bottom floor slabs must rest on the party wall leaves.

This yields a significant attenuation (coupling damping) of the vibration in the junction with the party wall leaf on both the source and receiving sides (in Figure 31, this is indicated by narrowing of the red line whenever it passes through the junction with a floor slab). Where a deepened foundation is present, a significant part of the energy is transferred to the earth surrounding the foundation and the foundation walls. The changes in the masses per unit area (mass of the foundation relative to walls) also result in attenuation. The use of heavier walls yields an additional benefit (and also results in superior insulation against direct sound transmission). Finally, vibration breaks can also be applied with the aid of resilient layers (such as when middleweight walls are installed).

For various reasons, the arrangement shown in Figure 31, is not always possible. A study yielded equivalent solutions for various other designs (see Figure 32) which also assured “enhanced acoustic comfort” (GROUP 1). In Figure 33, the arrangements yield structures which score even more highly ($D_{nT,w} \geq 62$ dB) (GROUP 2).

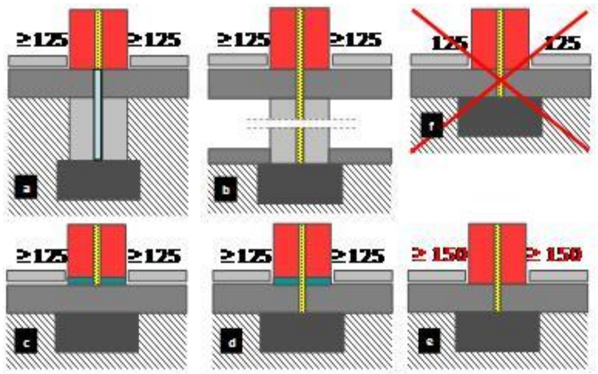


Figure 32: GROUP 1: schematic diagrams of foundation details geared to the attainment of $D_{nT,w}$ ≥ 58 dB (sufficient for enhanced acoustic comfort in apartment construction and normal acoustic comfort in terraced house construction). The schematic diagrams contain no detailed arrangements for damp-proofing, thermal insulation, etc. The walls employed have a mass per unit area of at least 125 kg/m², with the exception of solution “e”. (a) Traditional solution with deepened foundation; (b) solution involving crawl space/cellar; (c) solution with continuous (or general foundation) floor slab in which the walls are installed upon resilient strips (green line in the diagram); (d) as “c” but with discontinuous floor slab, allowing a few further dB of sound insulation to be attained. The break between the two floor slabs may be filled with a rigid thermal insulation board (PU, EPS, etc.); (e) this solution without resilient strips requires a discontinuous floor slab and party wall leaves with a mass per unit area of >150 kg/m²; the break between the two floor slabs in figures (d) and (e) may be filled with a rigid thermal insulation board (PU, EPS, etc.) as an alternative to mineral wool. (f) This solution does NOT satisfy the requirements for enhanced acoustic comfort, owing to the party wall leaves being too light.

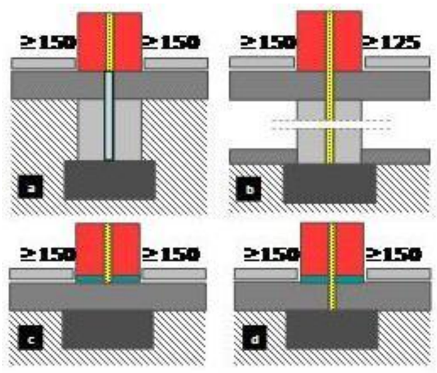


Figure 33: GROUP 2: schematic diagrams of acoustic principles of foundation details geared to the attainment of $D_{nT,w}$ ≥ 62 dB (sufficient for enhanced acoustic comfort in terraced house construction, and 4 dB superior to the criterion for enhanced acoustic comfort in apartment construction). The schematic diagrams contain no detailed arrangements for damp-proofing, thermal insulation, etc. The solutions are equivalent to those in Figure 32, but require masses per unit area of at least 150 kg/m².

6. E. BUILDING CODES APPLICABLE TO THE TRANSISTION TO THE ROOF STRUCTURE

The transition from the anchorless cavity wall to the roof structure is of major relevance to the acoustics: a risk exists of rigid coupling between the two cavity walls without ties; flanking sound may occur (flat concrete roofs); and a risk exists of leakage sound as a consequence of the solution to cold bridges on flat and sloping, lightweight roofs.

Sloping roofs comprising traditional designs and prefabricated rafters

In order to satisfy the acoustic principle of the double wall, the couplings are limited as far as possible at the transition to the roof: consequently, no continuous, rigid construction components that are rigidly connected to the party wall leaves (tile lattices and roof membrane may be continuous; the losses in this case are minor). Coupling between the two party wall leaves at the transition to the roof however does not generally constitute the greatest problem; instead, indirect airborne sound transmission and leakage sound is commonly the reason why enhanced airborne sound insulation is not attained.

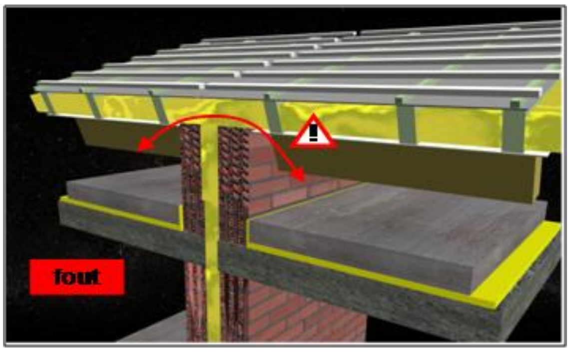


Figure 34: Leakage sound in an incorrectly executed arrangement

In order for a cold bridge to be avoided, the party wall leaves must not be continuous up to the membrane and roof covering (tiles, slates, etc.). This results in possible acoustic impairment between the top of the walls and the roof membrane/roof covering: as a result, sound is able to penetrate the interior finishing (gypsum board etc.) on the source side, continue through the thermal insulation (which barely offers any insulation against low frequencies), before finally passing through the interior finishing on the receiving side, from where it radiates (see Figure 34). The sound insulation for this transmission path is often little more than 50 dB and cannot therefore satisfy the requirements for apartments; also, under the roof is often precisely where the rooms most sensitive to noise, such as bedrooms, are located.

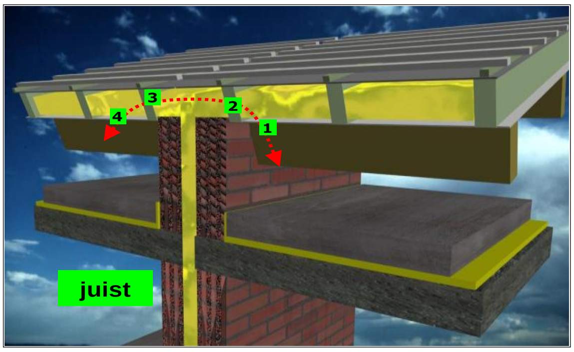


Figure 35: Schematic diagram of correct execution: by installation of the spars/ rafters against the party wall leaves, the leakage sound through 4 barriers becomes negligible

The sound insulation can however be enhanced easily at no additional cost by the following measures (see Figure 35):

1) Install a spar/rafter against the two party wall leaves and connect it to the party wall leaf for reasons of stability.
2) Use an acoustically absorbent product such as thermal insulation (e.g. mineral wool).

The transmission path for the indirect airborne sound transmission is then as follows: through the interior finishing on the source side / through the spar on the source side / through the acoustically absorbent mineral wool / through the spar on the receiving side / finally, through the interior finishing on the receiving side. The sound insulation for this transmission path is often substantially higher than 60 dB. The small cracks between the spars and the party wall leaves are irrelevant (on the one hand, they are closed off by the interior finishing; on the other hand, any sound penetration through small cracks will tend to be high-frequency, which is easily absorbed by the mineral wool).

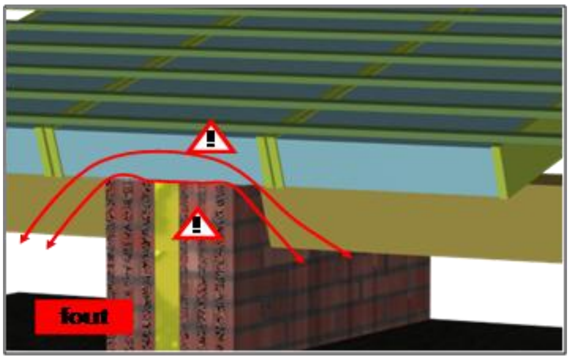


Figure 36: Incorrect execution: installation of the roof elements across the party wall eliminates the cold bridge, but significant sound transmission occurs via the two red arrows. The sound insulation may drop below 30 dB.

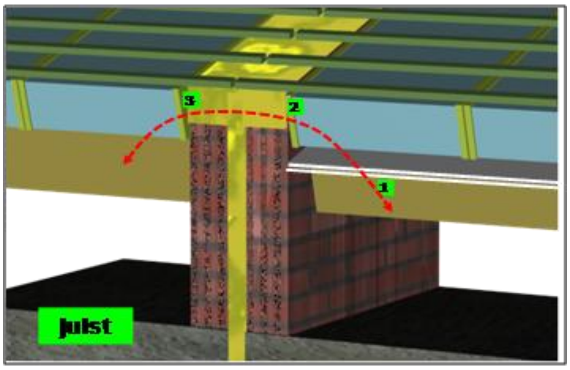


Figure 37: Schematic diagram of correct execution for normal acoustic comfort: the roof elements are installed against the party wall leaves

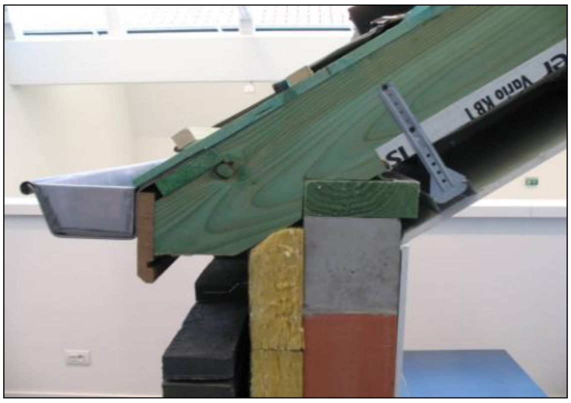


Figure 38: Photograph of installation of a decoupled suspended ceiling and transition to outer wall

Roof systems based upon homogeneous roofing elements

Such elements generally comprise a thin bottom layer (a few millimetres thick), 2 side elements and thermally insulating foam fill (e.g. PU). The sound insulation provided by such an element is weak (mass law). In order for cold bridges to be avoided, the roof elements are frequently installed progressively over the party wall (see Figure 36).

Unfortunately, this leads to very poor sound insulation in the lengthwise direction: the roof elements are much wider than the party wall, leading to a transmission path through the thin bottom layer, through the foam and back through the thin bottom layer into the adjacent building. Should an additional suspended ceiling not be installed, the airborne sound insulation between the two apartments may even fall below 30 dB. In addition, a major risk exists of sound leaks in the transition between the party wall and the roof elements, which can exacerbate the situation. A good solution here lies in installing the roof elements against the party wall leaves (Figure 37). Above the party wall leaves, mineral wool or some other porous, acoustically absorbent product is installed. For enhanced acoustic comfort, a decoupled suspended ceiling involving 2 x 12.5 mm gypsum panels (see Figure 38) must be installed on at least 1 side (preferably both). In a great many cases, the installation of such a suspended ceiling may be necessary in order for the external noise control requirements to be fully met.

An alternative effective solution may be to allow the roof elements to continue across the party wall, but then to install a suspended ceiling consisting of double gypsum panel in both apartments. (The increased coupling between the two party walls resulting from the continuous roof elements remains limited however owing to the thin bottom layer, with the result that the direct sound insulation is still very high.)

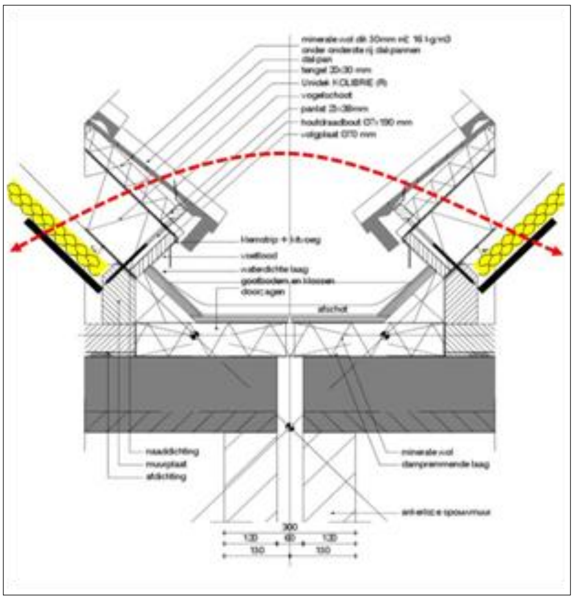


Figure 39: Schematic diagram of correct acoustic execution: detail at the party wall of roofs sloping towards each other constructed by means of lightweight roof elements

Figure 39 shows correct execution when the roof structures slope towards each other and meet at the party wall. Indirect airborne sound transmission (see the red dotted line) through the roofs with weak sound insulation (approx. 25 dB for the roof) has already led to problems on some construction sites. For enhanced acoustic comfort, suspended ceilings employing gypsum panels (see Figure 38) are required in both terraced houses; for normal acoustic comfort, this is necessary on one side only (if no particular exterior wall sound insulation is specified for external noise control).

Where this type of roof is continuous from a lower to a higher apartment, a similar risk exists of strong flanking sound transmission via the roof between the two apartments situated one above the other. Here too, a decoupled suspended ceiling consisting of a double gypsum panel must be installed (in both apartments if "enhanced acoustic comfort" is to be attained).

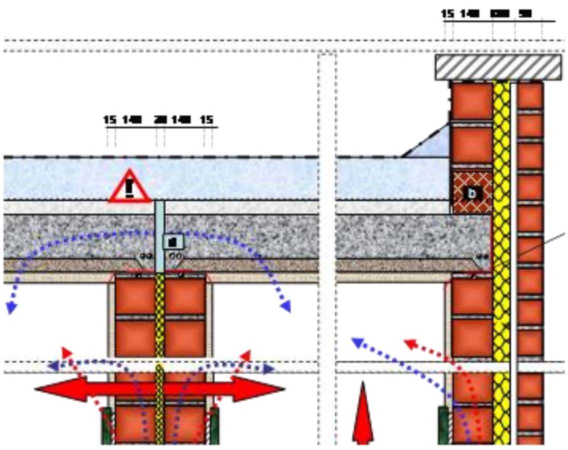


Figure 40: The sloping roof concrete must also be interrupted

Concrete roofs (Figure 40 and Figure 41)

Where a concrete roof structure is fitted, the general principle applies once again that no coupling should be present between the cavity wall leaves: the tie-less transition must be continuous up to the thermal insulation. **Consequently, allowing the sloping roof concrete to continue over the cavity substantially impairs the sound insulation, with the result that "enhanced acoustic comfort" is no longer attained.** The reason for this is the rigid coupling which is produced as a result between the two cavity walls and which largely negates the acoustic "double-wall effect". The coupling additionally causes strong flanking sound transmission, both via the roof slab (which is likely to be considerably lighter than the 500 kg/m² of the normal floor slabs) and via the cavity wall/roof slab transmission paths. The roof slabs and the sloping roof concrete may however be separated by a rigid thermal insulation such as PU/EPS.

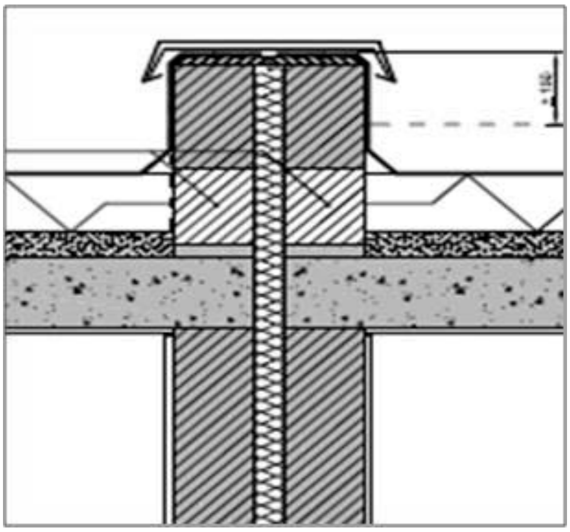


Figure 41: Alternative involving breaking-up of the water dispersal areas at a cavity wall without ties

A possible alternative is to divide the roof into two drainage areas at the level of the cavity (see Figure 41), as a result of which the party wall leaves remain perfectly decoupled.

Flat wooden roofs

On so-called "warm" flat roofs, the load-bearing slab is underneath. Where the slab continues over the party wall, a break is best made at the cavity in order to limit the flanking sound transmission via the slab and also in order for this coupling not to disrupt the double-wall acoustic effect. Attention should also be paid to indirect airborne sound transmission and leakages between the party walls and this slab. Here too, division into two drainage areas as shown in the concrete structure in Figure 41 is an alternative which should be considered.

So-called "cold roofs" (with the thermal insulation below the roof) should be avoided for thermal reasons. They also present acoustic problems. If a thermal bridge is to be avoided, the party wall leaves must also not continue up to the water seal. As with a sloping roof, a risk of indirect airborne sound transmission then exists (through the gypsum board finishing on the source side -> the thermal insulation -> back through the gypsum board finishing on the receiving side). Owing to this transmission path, the sound insulation is once again lower than 50 dB. If despite these issues, this solution has nevertheless been selected, the following measures must be taken, similar to the procedure for sloping roofs:

- *Where supporting beams run parallel to the walls: install the first supporting beam up against the party wall (and secure it to the latter, in order to improve stability).*
- *Where supporting beams penetrate the party wall: install an additional panel against the party wall between the beams, in order to provide additional sealing of the leakage sound path.*

6. F. BUILDING CODES FOR NON-SUPPORTING INTERIOR WALLS

In rare cases, the non-supporting walls also take the form of heavy walls (> approx. 250 kg/m²), and no particular acoustic measures are required. Where gypsum panels are employed for these walls, the lightweight metal profiles used for construction automatically lead to adequate decoupling of vibration from the remaining structure, with the result that additional flanking sound transmission is avoided (see Figure 43).

Frequently, however, the non-supporting walls consist of middleweight brickwork, and must be decoupled resiliently from the floor and ceiling slabs. For these middleweight, non-supporting structures, the transition to the ceiling slab never presents a problem since an installation foam must always be used in any case, for stability reasons. This also assures adequate acoustic decoupling. On many construction sites, however, decoupling is omitted at the transition to the floor slab. This leads to significant flanking sound transmission between the ceiling slab of the lower apartment and this non-supporting wall. **For this reason, this middleweight wall must be decoupled from the floor slab by means of a special resilient layer** if enhanced acoustic comfort is to be attained.

Figure 42: Gypsum blocks must also be decoupled resiliently from the floor slab by a suitable resilient strip. At the periphery, a permanently resilient joint is employed at the transition for the surface finishing.

Figure 43: Owing to the pliant properties of the gypsum boards and the inherent decoupling of the construction arrangement, the flanking sound transmission from the floor slabs is very limited.

For gypsum blocks (see Figure 42) and brick walls, special elastic underlayers exist and must be employed (refer to the manufacturers' documentation). From an acoustic perspective, the underlayers employed for non-supporting brick structures must also be effective when used beneath non-supporting concrete walls. Where the apartment structure consists exclusively of brick for both the supporting and the non-supporting walls, the resilient strips referred to above must therefore be installed between all walls and the floor slab such that a horizontal vibration break is created immediately above the floor slab throughout the building.

6. G. LIMITATION OF THE IMPACT SOUND

Direct and flanking transmission paths of impact sound

The power of impact sound injected into the structure (footsteps, bumps resulting from the moving of small items of furniture) is much greater than that caused by the incident airborne sound.

- *Where **rooms are located one above the other**, this sound is radiated not only by the ceiling slab (direct impact sound transmission); all walls which are rigidly coupled to the ceiling slab will also radiate a part of it to the rooms below (flanking impact sound transmission). This flanking impact sound transmission occurs for each junction, via a single flanking sound transmission path, to the rooms below, namely from the floor slab to the supporting wall (path "Df"). On a floor slab supported on four sides, this leads to a maximum of four flanking transmission paths. This lower number of flanking paths compared to the airborne sound transmission does not mean however that this flanking impact sound transmission can be ignored. Installation of a suspended ceiling alone will not generally be sufficient to assure adequate acoustic comfort.*
- *Only a single junction (the intersection between the party wall and the floor slab) exists between two **adjacent rooms**, and the total impact sound transmission is limited to only two flanking paths, namely "Ff" and "Fd". Where a floating floor is installed badly, however, this may be sufficient to prevent the anticipated acoustic comfort from being reached.*

Thermal and acoustic considerations

Just a few decades ago, the floors separating many apartment buildings were built based on a single concrete slab on which an equalisation screed was implemented that acted as a support for the floor covering. In the case where the latter was a hard covering (e.g. tiling or parquet), the impact sound insulation between superimposed apartments was very weak and thermal transmissions were inevitable. At present, to respect the new requirements in force, the separating floors must incorporate systems that make it possible to minimise transmissions of noise and heat already in the design stage. As such, acoustic insulation against impact sound not only depends on the floor covering but especially on the presence of a "vibration cut-off" in the floor implemented in practice by a resilient underlayer forming the base of a floating screed. Even if it is possible to limit the transmission of impact sound with the help of a more flexible covering (e.g. a carpet), this is no longer sufficient since the entry into force of the new acoustic standard in 2008. Impact sound insulation requirements must be respected from now on regardless of the floor covering put in place. While this provision leads to an obligation to fit floating screeds in the structure, it has the merit of avoiding disputes between neighbours entailed by altering floor coverings.

The 2008 standard which defines the performance levels to be reached for contact noises between apartments is NBN S 01-400-1. The requirements listed in the previous version of NBN S 01-400 (from 1977) concerned both the acoustic performances of products and the results obtained onsite. The new version of the standard exclusively imposes requirements concerning performances measured onsite. This new NBN S 01-400-1:2008 defines insulation criteria for impact sound based on the weighted standardised impact sound pressure level $L'_{nT,w}$ measured onsite. It represents the level of impact sound observed onsite, i.e. while taking account of all of the transmission paths of the noise (direct and flanking) and it can easily be checked by a measurement at the finished building with the help of a standardised tapping machine. The more the floor system is high-performing and the heavier the lateral walls, the lower this parameter $L'_{nT,w}$ (the quieter the tapping machine observed). This is why the requirements for increased acoustic comfort (50 dB) are expressed with a value in decibels that is lower than those of normal acoustic comfort (54 or 58 dB depending on the situation). The new criteria imposed by the standard are globally stricter than in the version of 1977, especially because it is possible to observe that even when the requirements listed in this former version are respected, occupants frequently complain about the lack of acoustic comfort with respect to impact sound.

By measurement or calculation, it is possible to determine that even with a heavy floor of 600 kg/m² combined with heavy walls, it is almost impossible to descend below an $L'_{nT,w}$ value of 65 dB. Even if the mass of the base floor plays a very important role, basing oneself solely on this does not make it possible to obtain very high insulations against impact sound; we remain far from the standard's criteria. To succeed, it is therefore essential to complete our floor with a more efficient system. The most common system, the floating screed, has therefore become essential in the construction of apartments because it makes it possible to render the insulation against impact sound practically independent from the choice of covering. The term "floating scree"' is used to cover both traditional screeds implemented on an acoustic sub-layer and so-called dry screeds, which are often made up of a high-density resilient product (e.g. mineral wool) combined with one or more floor panels (e.g. from gypsum fibres). Two parameters will therefore be important for the insulation against impact sound in floors separating apartments: the mass of the base floor (for equal thickness, better results are obtained with massive slabs than with hollow-core slabs) and the acoustic performance of the resilient layer, expressed in dB by the reduction of the weighted impact sound pressure level ΔL_w (measured in the laboratory and listed in the products' technical documentation). The higher this level, the more the resilient layer is efficient against impact sound. In general, we shall need membranes whose value ΔL_w goes from 18 dB to 21 dB (depending on the mass of the base floor) to respect normal acoustic comfort criteria and 21 dB to 25 dB for increased acoustic comfort. The essential equalisation layer which is implemented on top of pipes and wiring before the resilient layer is fitted will also play a role in the insulation against shock noises: if it is realised in cement in the traditional way, its mass will help the support floor to weaken the impact sound. If it is implemented with the help of an agglomerate that stays flexible or a resilient material (e.g. rubber granules, projected polyether) this material will act as the flexible interlayer or will help the resilient layer to soften the shock noises. If in contrast the equalisation layer is a light and rigid thermal insulation layer (e.g. a foamed concrete), this will not help the floor to dampen impact sound as this layer only provides a little mass to the support floor and is too rigid to play the role of "shock absorber" under the floating screed. However, by levelling out, this layer allows an optimal behaviour of the resilient layer under the floating screed and is in this sense strongly advisable.

The floors between apartments also play a role in the dampening of airborne sound between storeys, i.e. sound from television, voices, ringing telephones. The NBN S 01-400-1 standard from 2008 has also led to modifications in construction habits, mainly when an effort is made to respect increased acoustic comfort. To respect this, the base floor will need a surface mass of at least 500 kg/m² and a floating screed, which acts as acoustic insulation for aerial noises, whose ΔL_w value will be at least 24 dB.

From an energy viewpoint, the EPB regulations in the three regions also require a thermal insulation value between apartments which has an impact on the composition of floors. This demand relates to the maximum thermal transmission coefficient U_{max} (W/m²°K) which cannot exceed the value of 1 for the entire floor. This value, although it is less restricting than the value required for floors in contact with the ground, nonetheless has important implications for separating floors: the introduction of a thermal insulator becomes a necessity for respecting this criterion, since the value of 1 W/m²°K cannot be reached when using thin sub-layers (e.g. 5 mm of PE) and if the equalisation screed on the conduits is implemented traditionally in cement or even with an insulating concrete of less than 6 cm in thickness. However, the thickness of the insulator to be applied remains thin when using traditional thermal insulators (EPS, mineral wool, PU, etc); a thickness of 2 cm is sufficient to reach the criterion of the maximum thermal coefficient.

Combining energy and acoustic viewpoints: It is at the level of the equalisation screed on the conducts and the resilient layer that the arrangements adopted to respect acoustic criteria can occasionally enter into conflict with the thermal criteria: for the thermal aspect, the equalisation screed must be insulating and therefore light as a rule, whereas the heaviest possible equalisation screed is preferred from the acoustical point of view. We can nonetheless circumvent this contradiction in different ways as we shall see below.

In a construction where the base floor is relatively light, e.g. hollow-core slabs or a thin concrete slab, it is of interest to implement the heaviest possible equalisation screed to offset the weakness of the floor for insulating against airborne and impact sound. In this case, we will work with a traditional cement-based equalisation screed, to add mass to the base floor. This layer cannot fulfil the thermal criteria, so the resilient membrane will have to play the role of thermal insulator as well. We can then work with resilient interlayers made up of at least 2 cm of insulator with open cells (e.g. high-density rock wool, glass wool, panels of recycled polyurethane flakes, etc.). Finally, the reinforced floating screed which has a thickness of at least 6 cm, is to be implemented on a waterproof film rolled out on the insulator.

In the case where the base floor is heavy, e.g. a floor made up of a “prédalle” and concrete with a total thickness of at least 20 cm, several alternatives exist for fulfilling both the acoustic and thermal criteria. Firstly, the resilient layer + equalisation screed must have a combined thermal resistance R of at least 0.5 m²K/W. This is obtained for example with the help of an equalisation layer in insulating foamed concrete with a thickness of 6 cm combined with a 5 mm extruded polythene layer. To respect the acoustic requirements, we shall choose a resilient layer whose ΔL_w will at least be equal to 20 dB for normal acoustic comfort and 24 dB for increased acoustic comfort respectively. These criteria can also be reached by implementing a single thermal-acoustic layer, which fulfils the two roles, e.g. 5 cm of projected polyether, which will be adequate for normal acoustic comfort. Several systems that combine thermal equalisation layer and an acoustic interlayer exist in the market. To select them, please refer to the technical documentation, while ensuring respect for a thermal resistance R of at least 0.5 m²K/W for the entire unit from a thermal viewpoint and a ΔL_w that is at least equal to 20 dB or 24 dB depending on the level of comfort to be reached from an acoustic viewpoint.

Practical considerations

As seen here above, the solution to the direct and flanking impact sound transmission lies in application of a properly designed and executed “floating floor structure” (see Figure 44). The different steps of a correct execution are described below. More information on predicting the requirements concerning impact sound insulation and on impact sound transmission in general can be found in the extensive document of the TIATAB research project.

Proper installation and dimensioning of the floating floor structure is important not only in order for good impact sound insulation to be attained; it is also extremely important for airborne sound insulation (see above). Thorough monitoring on the construction site is then also necessary during installation of the vibration-damping layer and the sub-floor. Proper execution of a traditional floating floor is described step by step below.

Important: where resilient layers are installed as in **structural building concepts 3 and 5**, special measures must be taken: the edge strips must be installed before the levelling screed is applied.

Note: if the objective is merely to attain normal acoustic comfort during the construction of terraced houses, installation of floating floors – with the exception of the lowest occupied storey – may not be necessary where structural building concepts 1 to 3 are employed; a cavity wall without ties and with discontinuous floor slabs is required in this case.

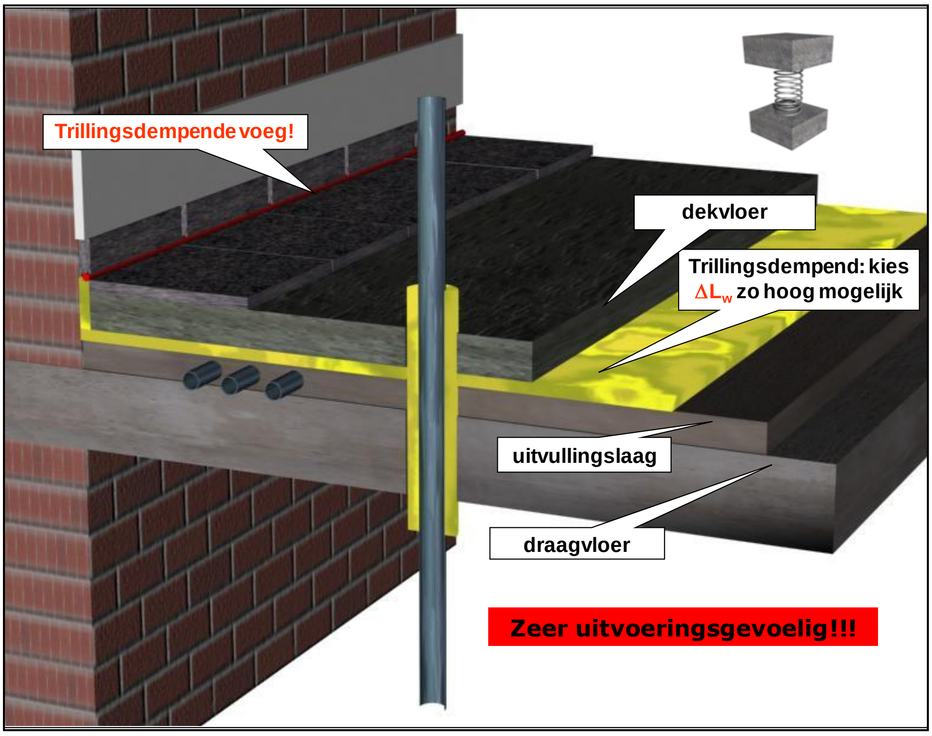


Figure 44: Structure of a traditional floating floor

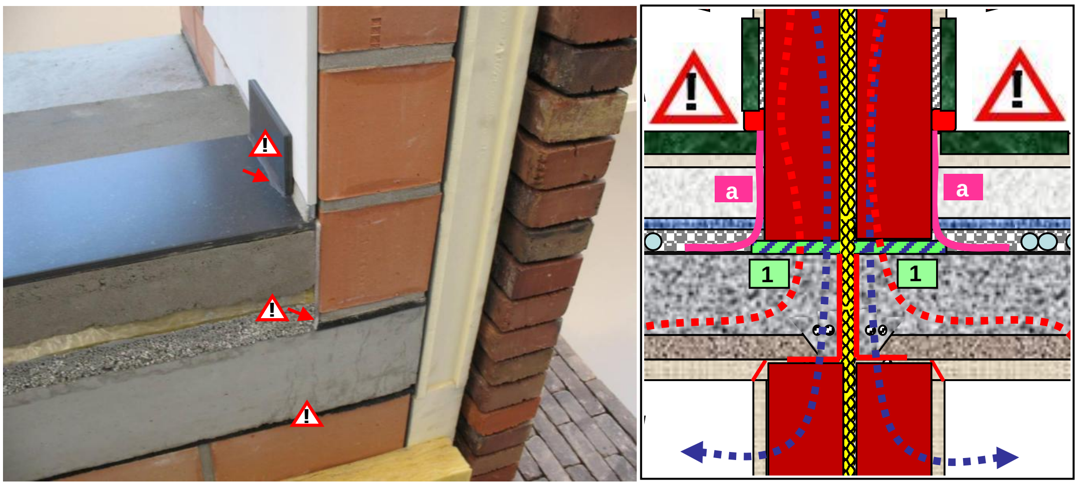
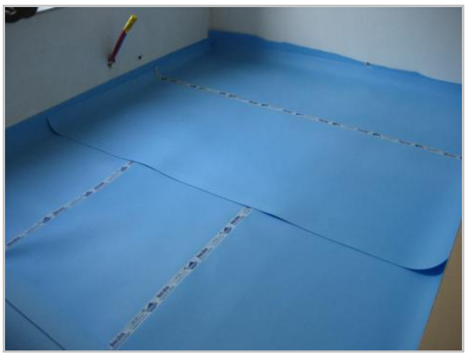


Figure 45: IMPORTANT: where resilient layers are employed (with middleweight construction shown in black in the left-hand figure, shaded green in the right-hand figure), the edge contact strips must at least reach the supporting floor and should preferably be folded onto it (see right-hand figure, point "a")



STEP 1 (only with structural building concepts involving resilient strips below the party wall leaves):

First install the edge contact strip such that the wall and the resilient joint are fully screened from the levelling screed and the floating floor. In practice, this means that the edge strip covers both a part of the supporting floor and the wall up to a little past the future finished floor level (see Figure 45). The edge contact strip must possess certain minimum elastic properties in order to fulfil its function as a horizontal vibration break. Smaller penetrations of the edge contact strip by electric power lines, heating, fresh and waste water pipes may be necessary but should be avoided as far as possible.

STEP 2:

Install a levelling screed. This layer should preferably have thermal insulation properties, in order for the energy performance regulations to be satisfied. The objective is the attainment of a smooth and level surface upon which the vibration-damping layer can be installed correctly.

STEP 3:

Clean the surface of the levelling screed such that it is free of any debris, spikes, etc. which present a risk of penetrating the resilient layer.

STEP 4:

Install the resilient layer and the edge strip (for structural building concepts with no resilient strip beneath the party wall leaves). Use products with an acoustic technical characteristic ΔLw greater than or equal to that specified in the "technical cards" for the structural building concepts attached to this chapter. Ensure that the layer adequately meets the edge contact strip and overlaps it if necessary. This requires particular care at difficult points such as

Figure 46: The various steps of proper execution of a floating floor

doorways, corner areas of the room, etc. As much care is needed here as for waterproof sealing in showers. Ensure that the resilient strips adequately overlap, and stick the individual strips firmly to each other with adhesive tape in order to prevent them from moving during screeding. Should resilient *mats* be used, they must be fitted sufficiently flush with each other; porous mats require the additional use of PE film for sealing. Avoid and prohibit personnel from walking over the resilient layers (pay attention to wheelbarrows, drilling work, ladders, etc.) and any activities which may potentially damage the vibration-damping layers, which are relatively susceptible to damage.

STEP 5:

Before beginning application of the sub-floor, check that the resilient layer screens it fully from the remainder of the structure such that a "vibration short-circuit" cannot occur.

STEP 6:

Install the screed. This must always be done with the necessary care and attention in order to ensure that the resilient layer is not punctured, damaged or moved at any point. For this reason, it is strongly recommended that the “tripod” stands be protected by vibration-damping material, that care be taken during manual work involving shovels, etc.

STEP 7:

Install the floor finishing. It is very important that the edge strip is not yet cut off (a frequent mistake): it now has the function of screening the tiles, lime mortar, etc. from the wall.

STEP 8:

Cut off the edge contact strip and install the skirting-boards using a line. Afterwards, the joint can be sealed by a permanently resilient jointing material (such as silicon).

ALTERNATIVES: various alternatives are available on the market by which the impact sound insulation can fitted/poured/projected, either in combination with the levelling screed or separately. Attention must be paid here to the layer depth of the product, which must be at least equal everywhere to that stated in the laboratory tests. The personnel involved in pouring/projecting the insulation layer must have appropriate training and must carry out their tasks properly such that all possible obstructed areas (such as behind pipes) receive the necessary layer depth. Installation of an additional vibration-damping layer in the form of a low-cost vibration-damping film may provide additional security.

6. H. BUILDING CODES AND TECHNICAL CONSTRAINTS UPON THE USE OF RESILIENT STRIPS UNDER WALLS OR SLABS

Although installation of these resilient intermediate layers delivers a genuine acoustic improvement, attention should nevertheless be given to a number of constraints and difficulties during execution which may inhibit their effectiveness in practice. For this reason, particular attention should be paid to the following aspects.

- *Where standard resilient intermediate layers are employed, this technique should, for acoustic reasons (i.e. not owing to the stability), be limited to buildings with no more than five storeys. For higher buildings, recourse should be made to specific (and more expensive) products for the resilient layers. Each type of resilient layer delivers ideal acoustic performance under a certain load. Should this load become excessively high, the product loses its resilient properties. This maximum load is appreciably lower than the maximum compressive strength for structural analysis purposes. This stipulation must obviously be checked when the technology in question is being used.*

- *As a result of large glazed areas, exterior walls frequently include columns and beams, which obviously prevent a resilient layer from being fitted. As such, this does not constitute an acoustic problem: the flanking sound transmission is negligible in such type of exterior walls (except where glass panels are continuous to the adjacent rooms). Nor does settlement of the walls upon the resilient layers constitute a problem with regard to the rigid exterior wall; the greatest settlement caused by the resilient layer occurs at the beginning of the load, when the first rows of brickwork are built up above the resilient strips. Once the wall has reached half a storey in height above the resilient layer, further settlement is negligible (and is asymptotically small with respect to time). In order to prevent cracks, a thin impact sound insulation film should ideally be placed between the concrete column and the brickwork.*

- *This arrangement may also improve the acoustic properties in buildings in which beams and columns are employed in combination with supporting brickwork. For this purpose, however, attention should be paid to the acoustic decoupling between the floor slabs and the party walls on the one hand and between the party wall leaves on the other. The resilient layer must be interrupted where the floor slabs meet the columns. If reinforced concrete beams are planned serving as intermediate supports for the supporting floor, the resilient material must be fitted on top of the beam. Where this is the case, the beam and the supporting floor will not be poured simultaneously.*

- *At the bearing point of the beams upon the brickwork, particularly of metal beams which are integrated into the thickness of the floor slab, the compression strength of the resilient intermediate layer may be exceeded. It is therefore generally necessary to interrupt this membrane, which may however result in a reduction in the acoustic performance.*

- *Studies by various manufacturers have shown that the seismic strength and fire-resistant properties of structures produced in this way are generally somewhat superior to those of comparable structures without resilient intermediate layers.*

- *When using resilient interlayers underneath concrete slabs, it is absolutely necessary to cut through the plastering. This is not only necessary to obtain optimal acoustic performances, it is also necessary to avoid serious damage in the plastered walls. Though the creep of the resilient layers is extremely small, this can still induce the cracking of the plaster!*

6. I. POINTS TO CONSIDER AT THE JUNCTIONS WITH EXTERIOR WALLS

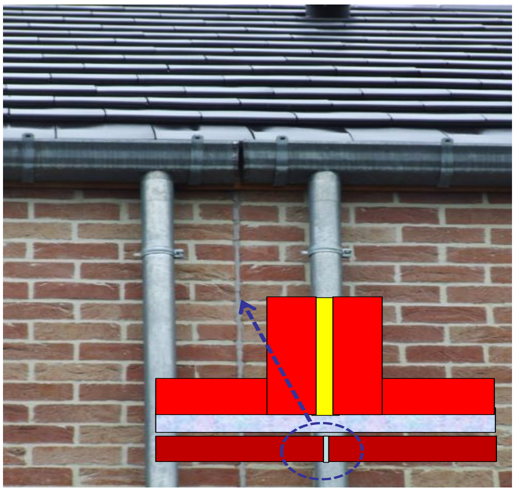


Figure 47: Interruption of the outer party wall leaf

Under no circumstances should the **inner**cavity wall leaf be continuous from one terraced house or apartment to the next: here too, the cavity clearance of 4 cm must be observed.

The **outer**cavity wall leaf is linked by ties to the inner cavity wall leaf. It is therefore also advisable for this outer cavity wall leaf to be interrupted by a fine joint (which may be filled with silicon, see Figure 47) if enhanced acoustic comfort is the objective.

6. J. PARTY WALLS ADJOINING UNDEVELOPED PLOTS AND ANCHORLESS CAVITY WALL STRUCTURES (WITHOUT ANY TIES)

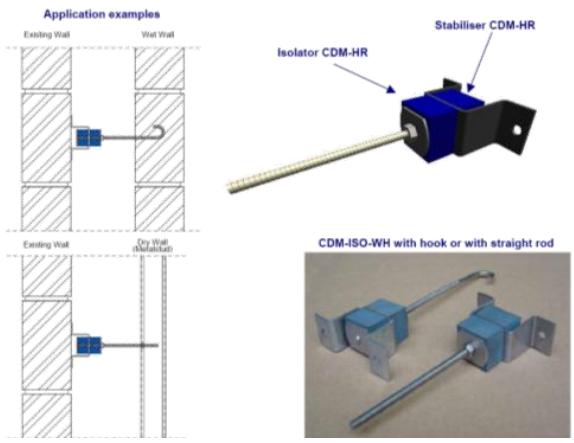
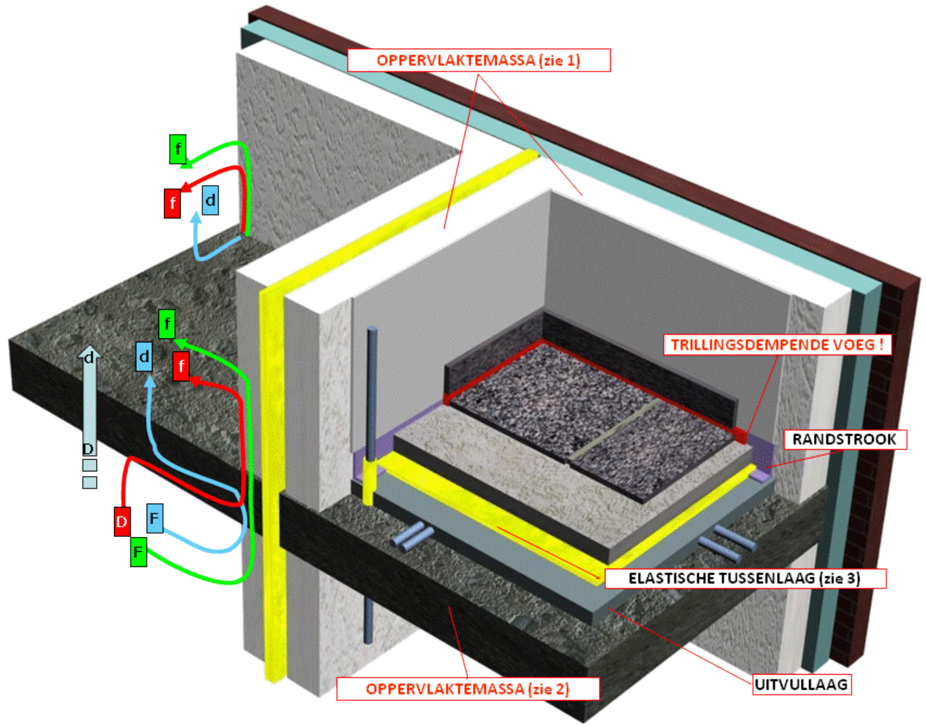


Figure 48: Party walls adjoining undeveloped plots can be erected in accordance with the principle of cavity walls without ties, but with special vibration-decoupled links between the two party wall leaves

In some cases, an adjoining apartment building or terraced house may not be built until later. Issues of thermal insulation, protection against rain and airtightness then arise. For lower apartment buildings and terraced houses, this can be resolved by the erection of the second party wall leaf. In order to assure the stability of this leaf, it is fixed to the first party wall leaf by means of a cavity wall tie. In order for the undesirable influence of this fixing to be limited, it is advisable to use special vibration-decoupled ties (see Figure 48). This also assures the first builder of a high level of acoustic comfort in the future.

Besides the constraints upon the load direction, this also has certain minor acoustic drawbacks. The coupling damping for example is reduced somewhat via the foundation by virtue of the fact that the party wall is not interrupted by the lowest floor slab (resulting in loss of one or two dB for the sound insulation between the two apartments; despite this, enhanced acoustic comfort can still be attained); at the same time, this also means somewhat poorer internal sound insulation for the apartment building which is to be erected later, owing to the increased flanking sound transmission to the rooms situated above.

STRUCTURAL BUILDING CONCEPT 1: Structures with DISCONTINUOUS FLOOR SLABS and a party wall in the form of HEAVY CAVITY WALLS WITHOUT TIES



GENERAL CONSTRUCTION PRINCIPLE (see above schematic diagram)

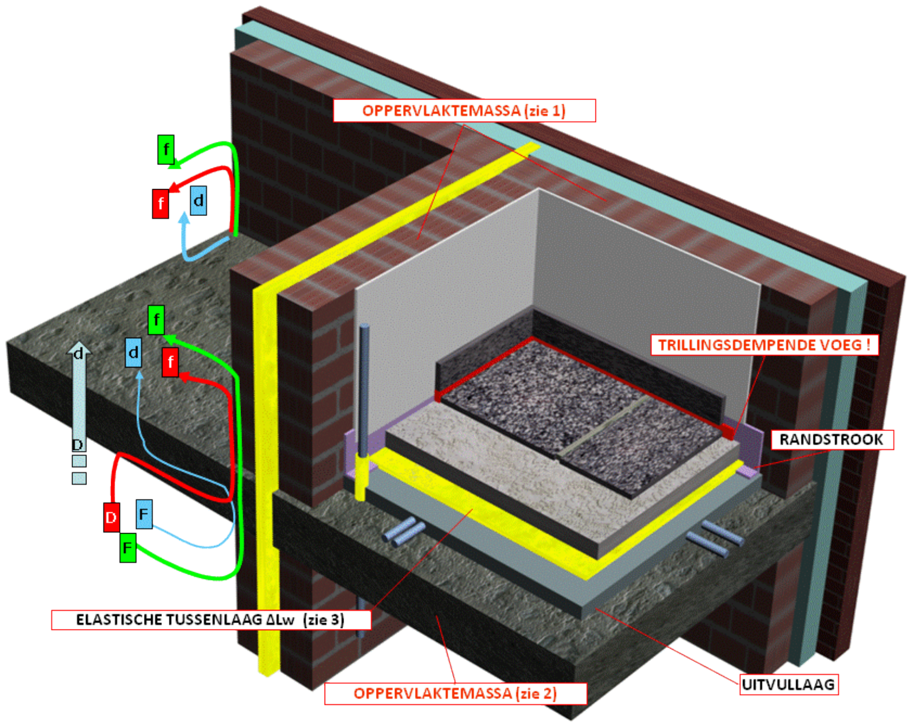
The party wall between two apartments or terraced houses comprises two heavy party wall leaves (each of at least 250 kg/m², for example sand-lime brick or concrete) with a cavity of 4 cm, with no rigid contact (including ties) between them. The only exception to this rule is the situation involving the foundation and the transition to the roof. In this case, special building codes apply both to the foundation (support of the lowest supporting floor, deepened foundation or resilient layers, etc.) and to the transition to the roof. Provided all building codes are followed meticulously, the party wall acts as a good acoustic double wall, and no or scarcely any flanking sound transmission occurs, as a result of which very high sound-insulation values are attained. Walls constructed from solid sand-lime blocks with a thickness of 15 cm or certain concrete blocks satisfy the requirements for the mass per unit area.

FOUNDATION and LOWEST SUPPORTING FLOOR	Variant 1	Variant 2	Variant 3	Variant 4
Selection of foundation and lowest supporting floor	Group 2	Group 2	Group 3	Group 2
Floating floor ΔLw above lowest supporting floor (3)	≥ 22 dB	≥ 22 dB	≥ 22 dB	≥ 22 dB
HIGHER SUPPORTING FLOORS				
Coupling between supporting floors at party wall	NO	NO	NO	NO
Support on the leaf of the party wall	YES	YES	YES	YES
Support on the other supporting walls	YES	YES	YES	YES
Mass per unit area m" of the supporting floor (2)	≥ 350 kg/m²	≥ 400 kg/m²	≥ 500 kg/m²	≥ 350 kg/m²
Floating floor ΔLw (3)	≥24 dB	≥22 dB	≥24 dB	≥28 dB
ΔLw situation non-bedroom above bedroom (3)	≥24 dB	≥22 dB	≥24 dB	≥28 dB
RESILIENT LAYERS				
Above wall/beneath supporting floor (ceiling)	None	None	None	None
Beneath wall/above (supporting) floor	None	None	None	None
WALLS				
1) Party wall				
Mass per unit area m" of the party wall leaf 1 (1)	≥ 250 kg/m²	≥ 250 kg/m²	≥ 250 kg/m²	≥ 250 kg/m²
Mass per unit area m" of the party wall leaf 2 (1)	≥ 250 kg/m²	≥ 250 kg/m²	≥ 250 kg/m²	≥ 250 kg/m²
Cavity width	≥ 4 cm	≥ 4 cm	≥ 4 cm	≥ 4 cm
Cavity filling limitation if rigid thermal material used	≤ 2 cm	≤ 2 cm	≤ 2 cm	≤ 2 cm
Connections between party wall leaves	NO	NO	NO	NO
2) Other supporting walls				
Mass per unit area m"	≥ 250 kg/m²	≥ 250 kg/m²	≥ 250 kg/m²	≥ 250 kg/m²
Break inner cavity wall leaf at party wall	YES	YES	YES	YES
Break outer cavity wall leaf (façade)	Preferably	Preferably	YES	Preferably
3) Non-supporting walls	≥ 250 kg/m²			≥ 250 kg/m²
Mass per unit area	As preferred	As preferred	As preferred	As preferred
Resilient layer beneath wall (above wall: always)	YES	YES	YES	YES
Decoupling with supporting walls	Preferably	Preferably	Preferably	Preferably
RESULT (indication of NAC/EAC applies only to apartments; stricter requirements apply to terraced houses)				
AIRBORNE SOUND INSULATION – In the vertical plane	**≥ 54 dB (NAC)**	**≥ 54 dB (NAC)**	**≥ 58 dB (EAC)**	**≥ 58 dB (EAC)**
AIRBORNE SOUND INSULATION – In the horizontal	**≥ 62 dB (EAC)**	**≥ 62 dB (EAC)**	**≥ 62 dB (EAC)**	**≥ 62 dB (EAC)**
IMPACT SOUND INSULATION – In the vertical plane	**≤ 58 dB (NAC)**	**≤ 58 dB (NAC)**	**≤ 50 dB (EAC)**	**≤ 50 dB (EAC)**
IMPACT SOUND INSULATION – In the horizontal	**≤ 50 dB (EAC)**	**≤ 50 dB (EAC)**	**≤ 50 dB (EAC)**	**≤ 50 dB (EAC)**

PRIMARY RISKS and ERRORS DURING EXECUTION

Decoupling between party wall leaves/Support of floor slabs on all supporting walls/Incorrect dimensioning and installation of floating floors/On lighter supporting floors (350 kg/m², e.g. hollow core slabs with topping), a better floating floor is required in order to compensate for the lack of airborne sound insulation of the supporting floor/Rigid coupling of skirting-board to floor/Decoupling under non-supporting walls/Inner cavity wall leaf too light/Details of transition to sloping roof/Leakage sound via shut system (ventilation or extractor hood ducts)/Floor slab too light (care required with beam-and-block systems)

STRUCTURAL BUILDING CONCEPT 2: Structures with DISCONTINUOUS FLOOR SLABS and a party wall in the form of MIDDLEWEIGHTCAVITY WALLS WITHOUT TIES

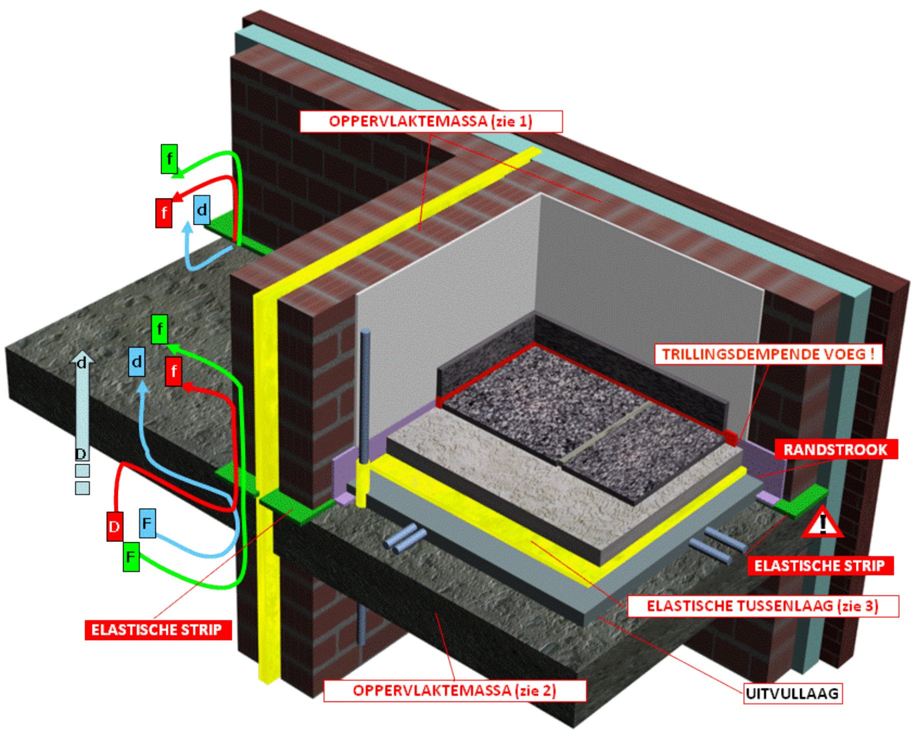


GENERAL CONSTRUCTION PRINCIPLE (see above schematic diagram)

The party wall between two apartments or terraced houses comprises two middleweight party wall leaves (each of at least 125 kg/m²), with a cavity of 4 cm, with no rigid contact (including ties) between them. The only exception to this rule is the situation involving the foundation and the transition to the roof. In this case, special building codes apply both to the foundation (support of the lowest supporting floor, deepened foundation or resilient layers, etc.) and to the transition to the roof. Horizontal: provided all building codes are followed meticulously, the party wall acts as a good acoustic double wall, and no or scarcely any flanking sound transmission occurs, as a result of which very high sound-insulation values are attained. Vertical: in this structural building concept, very heavy concrete slabs must be used in order to prevent flanking sound transmission.

FOUNDATION and LOWEST SUPPORTING FLOOR		Variant 1	Variant 2	Variant 3	Variant 4
Selection of foundation and lowest supporting floor		Group 2			
Floating floor ΔLw above lowest supporting floor (3)		≥ 22 dB			
HIGHER SUPPORTING FLOORS					
Coupling between supporting floors at party wall		NO			
Support on the leaf of the party wall		YES			
Support on the other supporting walls		YES			
Mass per unit area m" of the supporting floor (2)		≥ 400 kg/m²			
Floating floor ΔLw (3)		≥20 dB			
ΔLw situation non-bedroom above bedroom (3)		≥23 dB			
RESILIENT LAYERS					
Above wall/beneath supporting floor (ceiling)		None			
Beneath wall/above (supporting) floor		None			
WALLS					
1) **Party wall**					
Mass per unit area m" of the party wall leaf 1 (1)		≥ 150 kg/m²			
Mass per unit area m" of the party wall leaf 2 (1)		≥ 150 kg/m²			
Cavity width		≥ 4 cm			
Cavity filling limitation if rigid thermal material used		≤ 2 cm			
Connections between party wall leaves		NO			
2) **Other supporting walls**					
Mass per unit area m"		≥ 150 kg/m²			
Break inner cavity wall leaf at party wall		YES			
Break outer cavity wall leaf (façade)		Preferably			
3) **Non-supporting walls**					
Mass per unit area		As preferred			
Resilient layer beneath wall (above wall: always)		YES			
Decoupling with supporting walls		Preferably			
RESULT (indication of NAC/EAC applies only to apartments; stricter requirements apply to terraced houses)					
AIRBORNE SOUND INSULATION	In the vertical plane	TOO WEAK			
	In the horizontal	**≥ 62 dB (EAC)**			
IMPACT SOUND INSULATION	In the vertical plane	**≤ 58 dB (NAC)**			
	In the horizontal	**≤ 50 dB (EAC)**			
PRIMARY RISKS and ERRORS DURING EXECUTION					
Decoupling between party wall leaves/Support of floor slabs on all supporting walls/Incorrect dimensioning and installation of floating floors/Rigid coupling of skirting-board to floor/Decoupling beneath non-supporting walls/Inner cavity wall leaf too light/Details of transition to sloping roof/Leakage sound via shut system (ventilation or extractor hood ducts)/Floor slab too light (care needed with beam-and-block systems)					

STRUCTURAL BUILDING CONCEPT 3: Structures involving DISCONTINUOUS FLOOR SLABS, RESILIENT STRIPS and MIDDLEWEIGHT CAVITY WALLS WITHOUT TIES



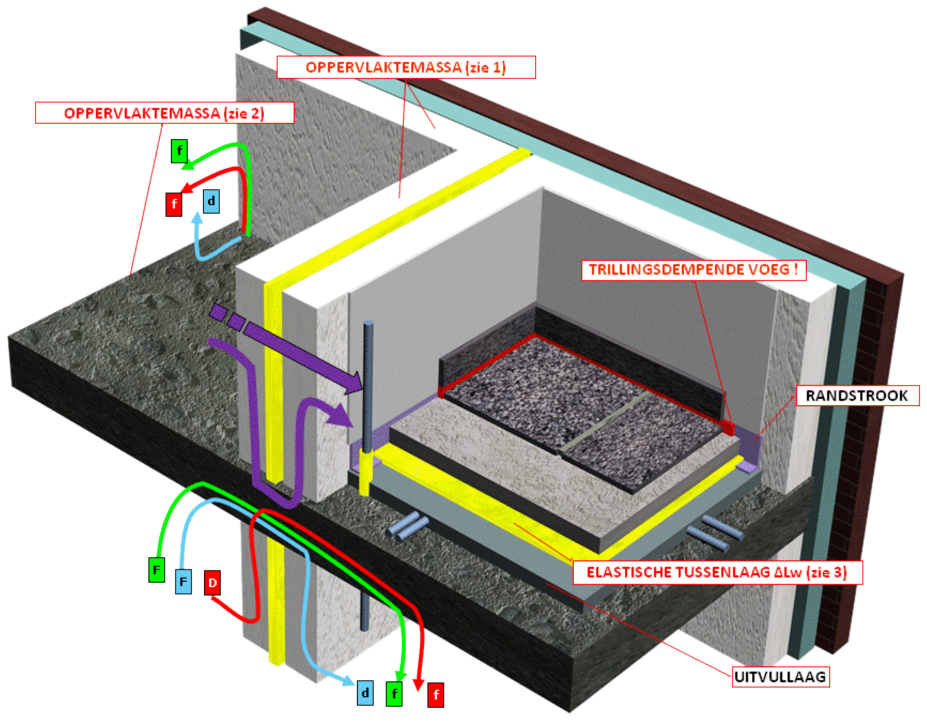
GENERAL CONSTRUCTION PRINCIPLE (see above schematic diagram)

*The party wall between two apartments or terraced houses comprises two middleweight party wall leaves (each of at least 125 kg/m^2), with a cavity of 4 cm, with no rigid contact (including ties) between them. The only exception to this rule is the situation involving the foundation and the transition to the roof. In this case, special building codes apply both to the foundation (support of the lowest supporting floor, deepened foundation or resilient layers, etc.) and to the transition to the roof. Horizontal: provided all building codes are followed meticulously, the party wall acts as a good acoustic double wall, and no or scarcely any flanking sound transmission occurs, as a result of which very high sound-insulation values are attained. Vertical: in order to limit flanking sound transmission in the vertical plane, **a resilient strip** must be installed beneath all supporting walls.*

FOUNDATION and LOWEST SUPPORTING FLOOR	Variant 1	Variant 2	Variant 3	Variant 4
Selection of foundation and lowest supporting floor	*Group 2*	*Group 2*	*Group 3*	
Floating floor ΔLw above lowest supporting floor (3)	*≥ 22 dB*	*≥ 22 dB*	*≥ 22 dB*	
HIGHER SUPPORTING FLOORS				
Coupling between supporting floors at party wall	*NO*	*NO*	*NO*	
Support on the leaf of the party wall	*YES*	*YES*	*YES*	
Support on the other supporting walls	*YES*	*YES*	*YES*	
Mass per unit area m" of the supporting floor (2)	*≥ 400 kg/m^2*	*≥ 350 kg/m^2*	*≥ 500 kg/m^2*	
Floating floor ΔLw (3)	*≥21 dB*	*≥21 dB*	*≥25 dB*	
ΔLw situation non-bedroom above bedroom (3)	*≥25 dB*	*≥25 dB*	*≥25 dB*	
RESILIENT LAYERS				
Above wall/beneath supporting floor (ceiling)	*None*	*None*	*None*	
Beneath wall/above (supporting) floor	*YES*	*YES*	*YES*	
WALLS				
1) <u>Party wall</u>				
Mass per unit area m" of the party wall leaf 1 (1)	*≥ 125 kg/m^2*	*≥ 150 kg/m^2*	*≥ 150 kg/m^2*	
Mass per unit area m" of the party wall leaf 2 (1)	*≥ 125 kg/m^2*	*≥ 150 kg/m^2*	*≥ 150 kg/m^2*	
Cavity width	*≥ 4 cm*	*≥ 4 cm*	*≥ 4 cm*	
Cavity filling limitation if rigid thermal material used	*≤ 2 cm*	*≤ 2 cm*	*≤ 2 cm*	
Connections between party wall leaves	*NO*	*NO*	*NO*	
2) <u>Other supporting walls</u>				
Mass per unit area m"	*≥ 125 kg/m^2*	*≥ 150 kg/m^2*	*≥ 150 kg/m^2*	
Break inner cavity wall leaf at party wall	*YES*	*YES*	*YES*	
Break outer cavity wall leaf (façade)	*Preferably*	*Preferably*	*YES*	
3) <u>Non-supporting walls</u>				
Mass per unit area	*As preferred*	*As preferred*	*As preferred*	
Resilient layer beneath wall (above wall: always)	*YES*	*YES*	*YES*	
Decoupling with supporting walls	*Preferably*	*Preferably*	*Preferably*	
RESULT (indication of NAC/EAC applies only to apartments; stricter requirements apply to terraced houses)				
***AIRBORNE SOUND INSULATION** – In the vertical plane*	***≥ 54 dB (NAC)***	***≥ 58 dB (EAC)***	***≥ 58 dB (EAC)***	
***AIRBORNE SOUND INSULATION** – In the horizontal*	***≥ 58 dB (EAC)***	***≥ 62 dB (EAC)***	***≥ 62 dB (EAC)***	
***IMPACT SOUND INSULATION** – In the vertical plane*	***≤ 58 dB (NAC)***	***≤ 50 dB (EAC)***	***≤ 50 dB (EAC)***	
***IMPACT SOUND INSULATION** – In the horizontal*	***≤ 50 dB (EAC)***	***≤ 50 dB (EAC)***	***≤ 50 dB (EAC)***	
PRIMARY RISKS and ERRORS DURING EXECUTION				

Decoupling between party wall leaves/Support of floor slabs on all supporting walls/Incorrect dimensioning and installation of floating floors/Rigid coupling of skirting-board to floor/Decoupling beneath non-supporting walls/Inner cavity wall leaf too light/Details of transition to sloping roof/Leakage sound via shut system (ventilation or extractor hood ducts)/Floor slab too light (care needed with beam-and-block systems)

STRUCTURAL BUILDING CONCEPT 4: Structures with CONTINUOUS FLOOR SLABS and DECOUPLED HEAVY CAVITY WALLS

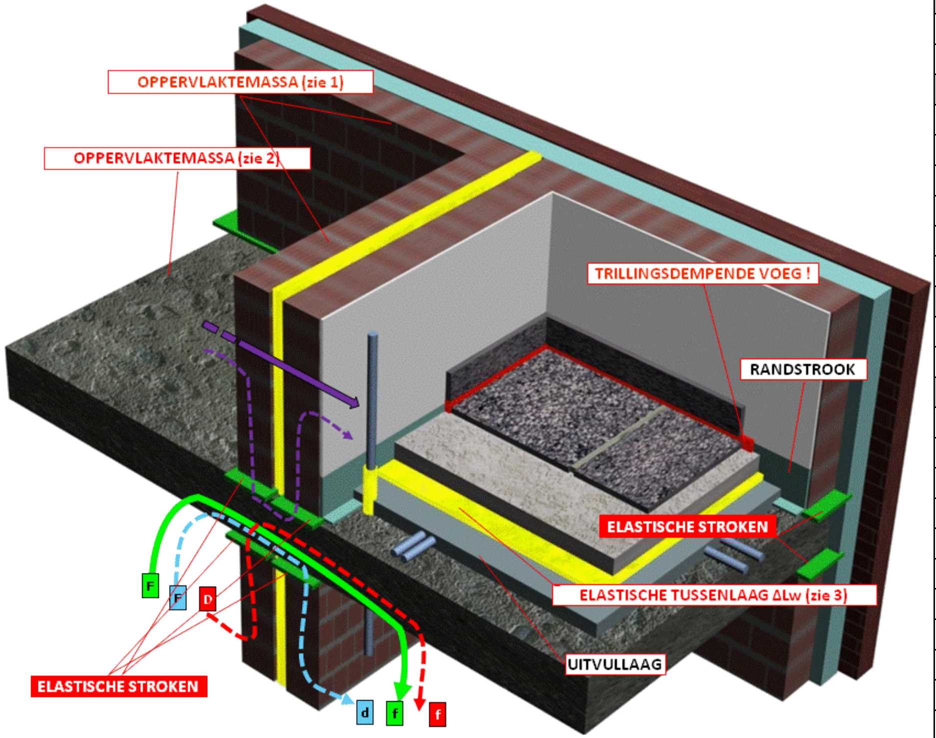


GENERAL CONSTRUCTION PRINCIPLE (see above schematic diagram)

The party wall between two apartments (not applicable to terraced houses) comprises two heavy party wall leaves (each of at least 250 kg/m², for example sand-and-lime brick or concrete) between which the thermal insulation is installed. The gap must be at least 3 cm; an air gap of 1 cm is retained if rigid thermal insulation is employed. Connections between the walls are permissible: the entire system does NOT act as an acoustic double-wall structure. The floor slabs may thus be continuous. In the vertical plane, enhanced acoustic comfort can be attained if very heavy floor slabs are employed in combination with a very good floating floor. Particular building codes apply both to the foundation (support of the lowest supporting floor, deepened foundation or resilient layers, etc.) and to the transition to the roof.

FOUNDATION and LOWEST SUPPORTING FLOOR		Variant 1	Variant 2	Variant 3	Variant 4
Selection of foundation and lowest supporting floor		*Group 1*	*Group 1*		
Floating floor ΔLw above lowest supporting floor (3)		*≥ 22 dB*	*≥ 24 dB*		
HIGHER SUPPORTING FLOORS					
Coupling between supporting floors at party wall		*NO*	*NO*		
Support on the leaf of the party wall		*YES*	*YES*		
Support on the other supporting walls		*YES*	*YES*		
Mass per unit area m" of the supporting floor (2)		*≥ 400 kg/m²*	*≥ 500 kg/m²*		
Floating floor ΔLw (3)		*≥22 dB*	*≥24 dB*		
ΔLw situation non-bedroom above bedroom (3)		*≥22 dB*	*≥24 dB*		
RESILIENT LAYERS					
Above wall/beneath supporting floor (ceiling)		*None*	*None*		
Beneath wall/above (supporting) floor		*None*	*None*		
WALLS					
1) Party wall					
Mass per unit area m" of the party wall leaf 1 (1)		*≥ 250 kg/m²*	*≥ 250 kg/m²*		
Mass per unit area m" of the party wall leaf 2 (1)		*≥ 250 kg/m²*	*≥ 250 kg/m²*		
Cavity width		*≥ 3 cm*	*≥ 3 cm*		
Cavity filling limitation if rigid thermal material used		*1 cm air gap*	*1 cm air gap*		
Connections between party wall leaves		*Permissible*	*Permissible*		
2) Other supporting walls					
Mass per unit area m"		*≥ 250 kg/m²*	*≥ 250 kg/m²*		
Break inner cavity wall leaf at party wall		*YES*	*YES*		
Break outer cavity wall leaf (façade)		*Not required*	*Not required*		
3) Non-supporting walls					
Mass per unit area		*As preferred*	*As preferred*		
Resilient layer beneath wall (above wall: always)		*None*	*None*		
Decoupling with supporting walls		*Preferably*	*Preferably*		
RESULT (indication of NAC/EAC applies only to apartments; stricter requirements apply to terraced houses)					
AIRBORNE SOUND INSULATION	*In the vertical plane*	***≥ 54 dB (NAC)***	***≥ 58 dB (EAC)***		
	In the horizontal	***≥ 54 dB (NAC)***	***≥ 54 dB (NAC)***		
IMPACT SOUND INSULATION	*In the vertical plane*	***≤54 dB (NAC)***	***≤50 dB (EAC)***		
	In the horizontal	***≤54 dB (NAC)***	***≤50 dB (EAC)***		
PRIMARY RISKS and ERRORS DURING EXECUTION					
Not for application on new terraced houses/Support of floor slabs on all supporting walls/Incorrect dimensioning and installation of floating floors/Rigid coupling of skirting-board to floor/Decoupling beneath non-supporting walls/Inner cavity wall leaf too light/Details of transition to sloping roof/Leakage sound via shut system (ventilation or extractor hood ducts)/Floor slab too light (care needed with beam-and-block systems)					

STRUCTURAL BUILDING CONCEPT 5: Structures involving CONTINUOUS FLOOR SLABS, RESILIENT STRIPS and MIDDLEWEIGHTCAVITY WALLS WITHOUT TIES

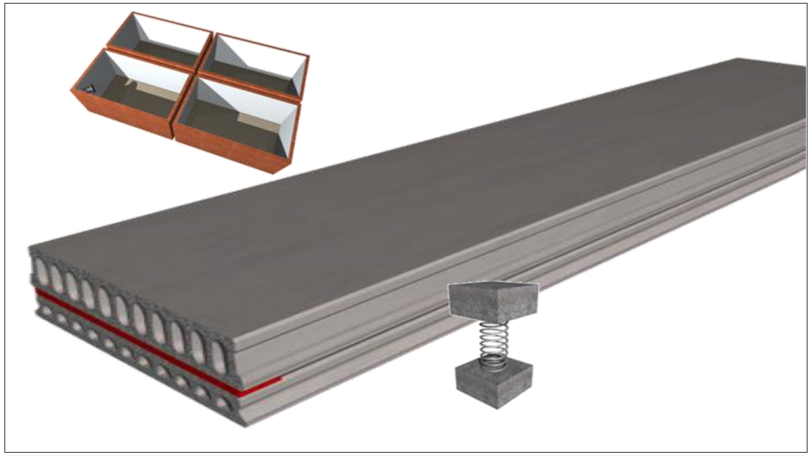


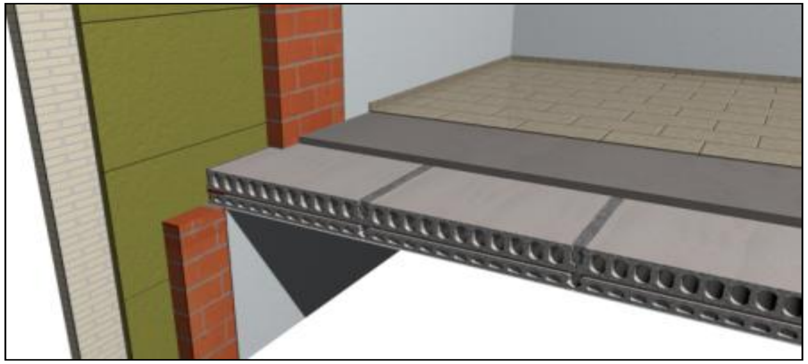
GENERAL CONSTRUCTION PRINCIPLE (refer to the schematic diagram above): the party wall between two apartments or terraced houses comprises two middleweight party wall leaves (each of at least 125 kg/m²), with a cavity of 4 cm, with no rigid contact between them. The only exceptions are the foundation and the transition to the roof, for which particular construction codes apply (support of the lowest supporting floor, deepened foundation or resilient layers, etc., transition to roof). The party wall leaves are vibration-decoupled from the continuous floor slabs by particular resilient joints. Horizontal: the party wall acts as a good acoustic double wall; the only flanking sound transmission occurs via the ceiling slab. Vertical: virtually no flanking sound transmission, owing to the resilient layers. The sound insulation is determined by the mass per unit area of the supporting floor and the efficiency of the floating floor.

FOUNDATION and LOWEST SUPPORTING FLOOR		Variant 1	Variant 2	Variant 3	Variant 4
Selection of foundation and lowest supporting floor		*Group 1*	*Group 1*		
Floating floor ΔLw above lowest supporting floor (3)		*≥ 22 dB*	*≥ 24 dB*		
HIGHER SUPPORTING FLOORS					
Coupling between supporting floors at party wall		*Continuous*	*Continuous*		
Support on the leaf of the party wall		*YES*	*YES*		
Support on the other supporting walls		*YES*	*YES*		
Mass per unit area m" of the supporting floor (2)		*≥ 400 kg/m²*	*≥ 500 kg/m²*		
Floating floor ΔLw (3)		*≥21 dB*	*≥24 dB*		
ΔLw situation non-bedroom above bedroom (3)		*≥25 dB*	*≥24 dB*		
RESILIENT LAYERS					
Above wall/beneath supporting floor (ceiling)		*YES*	*YES*		
Beneath wall/above (supporting) floor		*YES*	*YES*		
WALLS					
1) <u>Party wall</u>					
Mass per unit area m" of the party wall leaf 1 (1)		*≥ 125 kg/m²*	*≥ 125 kg/m²*		
Mass per unit area m" of the party wall leaf 2 (1)		*≥ 125 kg/m²*	*≥ 125 kg/m²*		
Cavity width		*≥ 4 cm*	*≥ 4 cm*		
Cavity filling limitation if rigid thermal material used		*≤ 2 cm*	*≤ 2 cm*		
Connections between party wall leaves		*NO*	*NO*		
2) <u>Other supporting walls</u>					
Mass per unit area m"		*≥ 125 kg/m²*	*≥ 125 kg/m²*		
Break inner cavity wall leaf at party wall		*YES*	*YES*		
Break outer cavity wall leaf (façade)		*Preferably*	*Preferably*		
3) <u>Non-supporting walls</u>					
Mass per unit area		*As preferred*	*As preferred*		
Resilient layer beneath wall (above wall: always)		*YES*	*YES*		
Decoupling with supporting walls		*Preferably*	*Preferably*		
RESULT (indication of NAC/EAC applies only to apartments; stricter requirements apply to terraced houses)					
AIRBORNE SOUND INSULATION	*In the vertical plane*	***≥ 54 dB (NAC)***	***≥ 58 dB (EAC)***		
	In the horizontal	***≥ 54 dB (NAC)***	***≥ 58 dB (EAC)***		
IMPACT SOUND INSULATION	*In the vertical plane*	***≤ 58 dB (NAC)***	***≤ 50 dB (EAC)***		
	In the horizontal	***≤ 58 dB (NAC)***	***≤ 50 dB (EAC)***		
PRIMARY RISKS and ERRORS DURING EXECUTION					

Decoupling between party wall leaves/Support of floor slabs on all supporting walls/Incorrect dimensioning and installation of floating floors/Rigid coupling of skirting-board to floor/Decoupling beneath non-supporting walls/Inner cavity wall leaf too light/Details of transition to sloping roof/Leakage sound via shut system (ventilation or extractor hood ducts)/Floor slab too light (care needed with beam-and-block systems)

STRUCTURAL BUILDING CONCEPT 6: SPECIFIC INDUSTRIAL CONCEPT WITH HOLLOW CORE SLABS





GENERAL CONSTRUCTION PRINCIPLE (see above schematic diagram)

The construction system is based upon cavity walls without ties: this results in very high sound insulation to adjacent rooms. The innovative aspect is that a form of horizontal cavity without ties is installed which breaks the structure over its entire surface. This also results in very high sound insulation in the vertical plane. The horizontal cavity without ties is achieved by the installation of floor slabs with two hollow core slabs, one above the other, which are insulated from each other by resilient strips and thermal insulation (EPB, energy performance for indoor climate). The lower hollow core slab supports only itself; the upper hollow core slab is supported on the lower slab at the level of the bearing on the walls by means of resilient strips, but has no rigid contact with it. The upper hollow core slab is heavier and is also capable of bearing the inner walls. The entire structure behaves as an acoustically optimal double wall, leading to very high airborne sound insulation. Owing to the horizontal cavity, virtually all flanking sound transmission is eliminated. The double floor also acts as a "floating floor" (mass-spring-mass system) and thus does not require a floating sub-floor.

FOUNDATION and LOWEST SUPPORTING FLOOR		Variant 1	Variant 2	Variant 3	Variant 4
Selection of foundation and lowest supporting floor		Group 1			
Floating floor ΔLw above lowest supporting floor (3)		N/A			
HIGHER SUPPORTING FLOORS					
Coupling between supporting floors at party wall		NO			
Support on the leaf of the party wall		YES			
Support on the other supporting walls		YES			
Mass per unit area m" of the supporting floor (2)		See			
Floating floor ΔLw (3)		N/A			
ΔLw situation non-bedroom above bedroom (3)		N/A			
RESILIENT LAYERS					
Above wall/beneath supporting floor (ceiling)		N/A, see manufactur			
Beneath wall/above (supporting) floor					
WALLS					
1) **Party wall**					
Mass per unit area m" of the party wall leaf 1 (1)		≥ 125 kg/m²			
Mass per unit area m" of the party wall leaf 2 (1)		≥ 125 kg/m²			
Cavity width		≥ 4 cm			
Cavity filling limitation if rigid thermal material used		≤ 2 cm			
Connections between party wall leaves		NO			
2) **Other supporting walls**					
Mass per unit area m"		≥ 125 kg/m²			
Break inner cavity wall leaf at party wall		YES			
Break outer cavity wall leaf (façade)		Preferably			
3) **Non-supporting walls**					
Mass per unit area		As preferred			
Resilient layer beneath wall (above wall: always)		N/A			
Decoupling with supporting walls		Preferably			
RESULT (indication of NAC/EAC applies only to apartments; stricter requirements apply to terraced houses)					
AIRBORNE SOUND INSULATION	In the vertical plane	**≥ 58 dB (EAC)**			
	In the horizontal	**≥ 58 dB (EAC)**			
IMPACT SOUND INSULATION	In the vertical plane	**≤ 50 dB (EAC)**			
	In the horizontal	**≤ 50 dB (EAC)**			
PRIMARY RISKS and ERRORS DURING EXECUTION					

This is an integral concept: contact must be made with the system supplier from the conceptual design stage; any deviation may result in reduction of the sound insulation/Decoupling between party wall leaves/Coupling between the two hollow core slabs/Transition details to sloping roof/Leakage sound via shunt system (ventilation or extractor hood ducts)/Floor slab too light (care needed with beam-and-block systems)

7. The problem of combining high façade sound insulation and the need for ventilation near noisy environments

7. A. INTRODUCTION

Residences located in noisy environments (e.g. airport noise zones, dwellings near busy traffic axes) usually require some serious soundproofing. In order to preserve the calm and health of the occupants, soundproofing of various living spaces is carried out on the building’s envelope. The traditional techniques used are based on two possible principles: the treatment of the exterior of the envelope or the treatment of interior of the envelope. But the necessary preservation of the interior sound environment must not be undertaken to the detriment of the interior air quality. For this reason, ventilation of buildings is also a necessity. This is where the problems arise: on the one part, from the necessity of sealing the residence as much as possible from noise, and thus from air; and on the other part, from the need to allow the optimal circulation of fresh air within those very same rooms. Below, we describe the existing technical means developed to make it possible to meet both of these seemingly incompatible needs.

7. B. SOUNDPROOFING METHODS

Introduction renovation versus new buildings

Soundproofing of residences can be undertaken on either an existing building, in which case one speaks of acoustic renovation, or in the context of a new build. While the techniques and materials used are most often very similar, important differences remain. The difficulty of soundproofing existing buildings is related to the need to intervene in an established geometry, with all the imaginable limitations (conservation of aesthetic aspects, living spaces, etc.). There are more over very significant acoustic and thermal constraints within which one must work. Within the context of soundproofing a new building, the choice of materials and techniques is more open, and also allows the modification of the architectural project if this is felt to be necessary.

One example, from amongst the different possibilities, is that of the roof. In the case of an acoustic renovation, one possible solution is to adapt the exterior envelope by adapting the roof. While this is technically feasible, it is also very work and cost intensive, because it requires the building of scaffolding and the careful removal of the roof covering and the water evacuation system. Once the soundproofing has been installed, everything that was removed must subsequently be re-installed. If the soundproofing being installed is very thick, additional care must be taken with the finishing in terms of the fascia boards, the chimney conduit and the water drainage system which may have been affected. This arduous operation is therefore often replaced by a solution involving the ceilings of the upper level rooms, or even - where possible - the roofing boards. Of course all aspects about thermal insulation need to be respected to avoid cold bridges, air tightness and condensation problems. In terms of a new building, many of the expenses are already included, whether an acoustic roof is to be installed or not, so in the end the only additional costs are for the materials used and the costs directly relating to their installation.

Development of a soundproofing plan

The soundproofing of a residence or a building follows a certain logic involving several successive stages that we will describe in the paragraphs below.

Objectives

The first stage is the definition of the objectives of the insulation. These objectives can be described in terms of a legal framework (for example, the airports of Liège-Bierset or Charleroi-Gosselies) or could respond to various standards (for example, NBN S01-400-1). Within the context of the soundproofing around Walloon airports, the level of the requirements is established on the basis of the geographical position of the house based on the Long-Term Development Plan. The insulation values are in this case between $D_{Atr}=D_{2m,ls,n,T}+C_{tr}=28$ dB and $D_{2m,ls,n,T}+C_{tr}=42$ dB. This is a very severe requirement!

Starting situation

In the case of an acoustic renovation, in order to optimise the effectiveness of the work and to limit the cost of implementing a solution, it is advisable to have an audit taken of the existing situation before starting any work. Understanding this initial acoustic situation will make it possible not only to determine the gains that are to be obtained, but also to locate the building's specific weaknesses. To measure the initial acoustic situation, it is possible to use the measurement standard ISO 140 Part 5 "*Field measurements of airborne sound insulation of façade elements and façades*". This standard specifies several evaluation methods, the most frequently used of which is the global loudspeaker method.

With this method, the loudspeaker is placed in one or more positions outside the building, with a 45° angle of sound incidence. The acoustic field produced must be stable and have a continuous spectrum within the range considered. The next step is to sweep the exterior of the façade being appraised using a microphone, then to measure the level of sound in the reception room. The reverberation time of the building must also be determined.

Once these measurements have been taken, it is possible to calculate the insulation using the level difference $D_{2m,ls,n,T}$. For a new building, the initial acoustic situation cannot be measured, of course. The acoustic study must be made on the basis of the construction plans and on the zones to be protected. This manner of proceeding is described in the following paragraph.

Choice of sites to treat

Depending on the insulation objectives and the values obtained during the measurement of the existing acoustic situation, it may be necessary to give the rooms buffer spaces, both in the case of an existing project and for a new building. These buffer spaces can be, for example, a hallway or connecting room. In practice, a margin of more or less 10 dB in the insulation between two adjacent sites is sufficient. This value of 10 dB corresponds approximately to the insulation value of an interior undercut door. Of course, this will be an estimate; the work must be carried out on a case by case basis.

Choice of techniques

Once the decisions have been taken on the rooms to be soundproofed and the objectives of the insulation, the soundproofing techniques and materials to be used must be selected. For the case of an acoustic renovation, these choices are obviously dependent on the initial values and constraints associated with the building. For a new build, there is more freedom to choose techniques and materials. The first treatment must be carried out on those façade elements with the weakest acoustic insulation. Improving or replacing the façade frames is usually necessary. Amongst other frequent weak spots are the shutter casings, the thermal infill panels in PU or PVC, and of course the ventilation systems. Subsequently, depending on the required values, treatment of the ceilings and even the walls may turn out to be necessary.

To determine the work to be planned, a calculation standard can serve as the basis for developing a computer program. This is covered in EN 12354 Part 3 “*Building acoustics. Estimation of performance in buildings from the performance of elements. Airborne sound insulation against outdoor sound.*” This standard makes it possible to estimate the airborne sound insulation of a façade comprising multiple elements. These elements can be the walls, one or more frames, the shutter casings, the ventilation systems or even a ceiling.

Based on the visible surfaces for each component, the known sound reduction indices R, and the size of the reception room the standard gives the equations that make it possible to calculate the standard acoustic insulation of a façade with a measurement of $D_{2m,ls,n,T}$. These calculations can be expressed in octave bands or octave-thirds, or more simply from a global point of view. The only limitation is the knowledge of the insulation indices for the various elements that make up the façade. The contribution of the lateral transmission is usually negligible. However, depending on the rigidity of the elements and their attachment to the walls of the receiving room, the lateral transmission can contribute to the overall acoustic transmission, which can become significant in the case of very high requirements.

The standard EN 12354-3 can be encoded into a spreadsheet application, and its sheets then be linked to a database containing the information on the insulation indices of the various elements.

Below is one example of a possible representation of the standard in spreadsheet form. The division of the principle façade into several sub-façades, if necessary, makes it possible to reveal the weakest elements, for example between a façade made up of multiple plate glass windows and a ceiling situated under an unconverted attic space. Once the geometry of the rooms has been determined and the elements encoded, all that remains is to "tweak" the database for the materials that will meet the requirements. The following size guides can provide guidance for the amount of insulation necessary for each element of a façade. To achieve an insulation objective of a façade of X dB, the insulation for the glassed parts should be X dB, while for the walls and opaque parts (ceilings/roof) the insulation should be X+7 dB. For small construction elements like ventilation systems or shutter casings, the insulation must be X+10 dB in reference level $D_{ne,w.}$

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Occupant du logement		M. Mme Lejeune						N° de dossier :	12354			
2	PIECE	ID MAT.	COMPOSITION	OPTIONS	SURFACE (m²)	GLOBAL							
3	Chambre étage								Bruit routier				
4													
5	FACADE 1						MODIF		Longueur =	4,5 Mètres			
6	Eléments opaques (R	300	blocs béton creux 14 / laine 5 / briques pleines		7,8	47,0	☐		Largeur =	3,0 Mètres			
7	Vitrages (R)	510	66.2A/20/44.2A		3,0	42,0	☑		Hauteur =	2,4 Mètres			
8	Aération (Dne)	713	Colonne : caisson mdf + sonoflex + STB1		1	46,0	☑						
9	Elément suppl. 1			R en dB			☐		RECAPITULATIF				
10	Elément suppl. 2 (R)						☐		ELEMENT		SURFACE (m²)	Rp	
11	Global façade 1 (Rp)				10,8	42,6							
12									FACADE 1		10,8	42,6	
13	FACADE 2	On					MODIF		FACADE 2		7,2	47,0	
14	Eléments opaques (R	300	blocs béton creux 14 / laine 5 / briques pleines		7,2	47,0	☐		PLAFOND		13,5	49,0	
15	Vitrages (R)						☐		PAROIS INTERIEURES			---	
16	Aération (Dne)						☐		SURFACE TOTALE EN M²		31,5		
17	Elément suppl. 1			R en dB			☐						
18	Elément suppl. 2 (R)						☐		R' (indice d'affaiblissement appare			45,4	
19	Global façade 2 (Rp)				7,2	47,0							
20													
21	PLAFOND	On					MODIF		D2m,n,T global bruit route		40,7 dB(A)		
22	Toiture (R)	904	Etanchéité/agglo 18mm/LM/1PP1	Plate	13,5	36,0	☐						
23	Elément suppl. (R)						☐		Objectif à atteindre		40 dB(A)		
24	Doublage (R)	1002	Doublage plafond Acoustix +anti-vib (+13c		13,5	13,0	☑						
25	Elément suppl.			Dne			☐		Mesure état initial EDSI		-		
26	Global plafond (Rp)				13,5	49,0							
27									Elément le plus faible		FACADE 1		
28	PAROIS INTERIEURES	Off					MODIF		Remarques :				
29	Pièce tampon				-		☐						
30	Cloison (R)						☐						
31	Porte (R)						☐						
32	Elément suppl.			R en dB			☐						
33	Global parois int. (Rp)					---							
34													

7. C. PRINCIPLES OF SOUNDPROOFING

In the following paragraphs, we will lay out some of the main principles and techniques of soundproofing. This is not an exhaustive list of all construction elements, but rather a compilation of the elements most commonly found. One of the major problems, i.e. ventilation, is treated in an extensive chapter 7.D.

Frames

Regarding the window and door frames, two techniques are used in renovation: on the one part, improving the existing frames, and on the other part, replacing them with new pieces. Possible improvements in terms of window frames include the replacement of the glazing, the replacement of the existing rebate gaskets or the installation of grooved joints if the profile allows, and the installation of double-glazing. For an exterior door, the glazing can be changed as can the panels, and if the profile allows, a guillotine-type or schall-ex joint can be installed below the door in order to limit low air currents. Not all of these improvements will necessarily be possible. For example, the installation of double glazing depends on the constraints of the maximum thickness of the rebate, and of course the maximum weight that can be supported by the hardware and the profile. On the other hand, the replacement of a glass pane on an unsealed frame will not have a real improvement effect on the overall insulation, as possible leaks will strongly limit the potential gains.

Based on the improvements that are possible, one can estimate that the gain will vary between 1 dB and 5 dB, and even more if the frames allow. To obtain high levels of insulation, or in the event that the frames are difficult to improve, replacement is a more sure solution in terms of final results. The best frames, whether in wood, PVC or aluminium, can reach values of Rw+Ctr = 42 dB. This has been determined in laboratory tests carried out on samples that are usually 1.25 m x 1.48 m. In addition to the acoustic qualities of the glass, the quality of manufacture of the profile is important. The number of rebates, the number of closure points and the character, for example, of the metallic reinforcements in the PVC profiles are notably important. The higher the required level of insulation, the more these factors will play a role in the overall result.

Shutter casings

When they are present, monoblock shutter boxes in PVC or shutter casings are some of the elements that must be dealt with as a priority, firstly for technical reasons and secondly for acoustic reasons. Indeed, if the frames are changed, with profile dimensions that can be different by several centimetres, adapting the box panels is not easy, which can result in several acoustic leaks at the joints. What's more, as monoblock shutter boxes are often made up of a single PVC wall, the acoustic insulation at that point is strongly reduced. In terms of traditional shutter casings, the means of action is the utilisation of MDF wood panelling with a thickness of between 18 mm and 22 mm; a fibre insulation is recommended in order to limit the vibration effect inside the casing, which also improves the thermal performance of the element. Based on the insulation objectives, one or two panels can be installed, as well as a steel or lead sheet. The utilisation of sound-cancelling materials is also a possibility.

Laboratory tests on a traditional shutter casing made up of a single MDF 22 mm panel provided the following level differences: $D_{ne,w}$ (C;Ctr) = 44 (-1;-1) dB without rock wool; $D_{ne,w}$ (C;Ctr) = 56 (-1;-1) dB with 50 mm of rock wool on the lower front face.

These two values clearly demonstrate the importance of fibre insulation.

Acoustic and improved versions of monoblock shutter boxes can be made with aluminium walls, melamine sound absorbing foam or sheets made of lead or a sound-absorbing bituminous rubber material. The insulation levels obtained will thus be comparable to traditional casings.

Ceilings, floors and roofs

Depending on the building configurations, the requirements for high performance acoustic insulation often involve the treatment of the upper parts. It is therefore advisable to consider the performance improvement of the ceilings, roof or floors. The solutions that can be applied depend on the desired level of improvement, but even more on the architectural constraints related to the building.

Ceilings

In acoustic renovation, many ceiling improvement techniques exist, all based on the addition of mass and on separation. Independent and self-supporting metal-framed ceilings can be used to achieve this. False-ceiling profiles with anti-vibration suspension can also be used. Another possibility is to use damping materials composed of wood fibres or compressed cellulose. Whichever solution is implemented, it is essential to fill in the space created by the plenum with an absorbent fibre material such as rock wool, glass wool or natural insulation. It can be finished using one or two plaster sheets; fibro cement sheets can also be installed.

The expected gains can be between 10 dB and 20 dB, depending on the techniques used. For sloped ceilings, it may be necessary to remove the existing ceiling in order to limit the loss of space and height under the ceiling. In this case, it is necessary to work within the thickness of the frame.

Floors

As an alternative to lining the ceiling, floor lining can also be a possibility. It is less difficult than the ceiling solution, although the maximum gains are generally lower, as well. An improvement of 10 dB to 15 dB can be possible. Dry screed panels made up of reinforced plaster sheeting and a thin layer (usually 10 mm thick) of fibrous insulating material, exist on the market and can be used for this application. To increase their efficiency, these panels can be combined with a 50 mm thick high-density fibre underlayer. Wood panels on acoustic panelling can also be used. As with the ceiling solutions, the two principles to respect are the increase of the mass surface and the separation of the layers.

Roof

This solution is more onerous for an acoustic renovation than for a new build. The principle is to preserve as much as possible the interior space, and to use the exterior roof as the primary noise barrier. The first possibility is to use a rigid roof underlayment. There exist on the market rigid roof underlayments made of fibro cement or the equivalent, 3 mm to 4 mm thick. Just using these panels provides an appreciable gain of several decibels, compared to a conventional roof. The thickness of these panels can vary from a few millimetres to several centimetres. Wood panels can also be used. For very high performance acoustics, the utilisation of specialised acoustic materials and complexes is inevitable. These acoustic systems for the roof can be composed of fibre materials and wood panels; they are often installed on the roof after putting in place one to two layers of compreg and fibro cement board. Laboratory measurements have demonstrated that such acoustic complexes make it possible to reach an insulation level superior to R_w = 50 dB.

To do this, the structure of the framework must be verified in order to ensure that it can support the additional load of 40 kg/m² to 50 kg/m².

7. D. VENTILATION

Introduction

Most existing habitations are ventilated with natural infiltration by leakage through cracks and fissures, mainly in the building frame. Soundproofing a building has a direct impact on improving air tightness. The need for air exchange in residential buildings is undisputed. Both the supply of fresh air containing vital oxygen and the exhaust of internal pollutants produced by human activity, the human metabolism or certain materials are of crucial importance to the health and comfort of residents. The necessary exchange of the air should preferably be achieved with consideration for the issues of energy and of acoustic and thermal comfort. Controlled ventilation, i.e. without infiltration caused by deficiencies in the building envelope or open windows, is then extremely important. It therefore follows that a ventilation system must be installed in the building or dwelling.

The use of controlled ventilation flows enables both the air quality and the energy consumption and thermal comfort to be kept under control. In addition, the ventilation system exerts an influence upon the energy performance of the building itself. In the winter, the supply of colder outdoor air is coupled with a certain heat loss, which can however be limited by appropriate measures. It therefore comes as no surprise that the EPB regulation is concerned not only with energy performance, but also with the indoor climate in general. For example, it attaches importance to the air tightness of buildings, in order to limit uncontrolled and undesired infiltration, and also requires a minimum capacity in terms of airflow in order to guarantee adequate air quality.

For monitoring of the acoustic comfort, a number of guidelines must be observed, some of which are described in the EPB regulation, as a function of the selected ventilation system, the environmental noise exposure, the intended use of the space, and the composition and orientation of the outside wall.

The present chapter discusses in turn the basic principles, the requirements for design and dimensioning, the energy-related aspects, and finally the comfort aspects, i.e. the thermal and acoustic comfort of ventilation systems. Comprehensive information on specific acoustic aspects of ventilation can be found in the relevant chapter of the Bouwdetailatlas (atlas of building details), Part 2, which concerns outside wall sound insulation. Full information on basic principles, design, and energy aspects of ventilation in the context of the EPB regulation is available for consultation in the form of BBRI information sheets [Ref. 7.1].

Basic principles

For ventilation to be effective, a number of basic principles must be observed relating to the supply, exhaust and through flow of the air. Outdoor air must be supplied to areas which are generally occupied for longer periods and in which contamination of the air is generally limited, i.e. "dry areas" such as living rooms, bedrooms, studies and children's playrooms. The contaminated air from areas with major contamination is exhausted to the exterior through "wet areas" such as kitchens, bathrooms, laundries and WCs.

Air flows freely from dry areas (air supply) to wet areas (air exhaust) via intermediate airflow vents in interior walls and doors, directly from dry to wet areas, and/or via intermediate rooms such as halls and stairways. In dry areas, at least one intermediate airflow vent must therefore be provided for the free exhaust of air, and in wet areas at least one intermediate airflow vent for its free supply. The intermediate vent may also be a gap beneath the door (or several gaps spread over several doors).

The pressure differential required for the air to circulate can be generated naturally (by wind or temperature differences) or mechanically (by fans). According to the nature of the force (natural or mechanical) employed for air supply and exhaust, four basic ventilation systems are distinguished. These are: “system A”, employing natural supply and exhaust; “system B”, employing mechanical supply and natural exhaust; “system C”, employing natural supply and mechanical exhaust; and “system D”, employing mechanical supply and exhaust.

The choice of the ventilation system has an impact upon the air quality in the building, the power consumption (electricity and heating requirements), the thermal comfort (risk of damp in the winter), the acoustic comfort (noise from outside or caused by the system), and the investment and operating costs. The different systems A, B, C and D are characterized by typical advantages and disadvantages. Mechanical ventilation systems for example generally score well in their air quality but poorly with regard to electricity consumption, noise exposure, and investment and maintenance costs. Conversely, natural ventilation systems offer benefits in terms of power consumption and acoustic comfort. By proper dimensioning, judicious selection of the ventilation components and careful installation, a number of typical disadvantages can however be substantially reduced. The power consumption for example can be limited by reduction of the air leakage loss in the ducts and by the installation of powerful fans. The risk of noise exposure from these mechanical systems can largely be reduced by measures including the use of properly dimensioned and located dampers.

Design and dimensioning requirements

Installation of a ventilation system is mandatory in new dwellings. During redevelopment work, too, a number of ventilation requirements must be taken into account under the EPB regulation. In the BBRI article entitled "De Energieprestatie-regelgeving voor gebouwen: nieuwe ontwikkelingen in Brussel en Wallonië" [Ref. 7.2], the requirements in force within the three Belgian regions are described with reference to the type of building and the nature of the planned work [Ref. 7.3 to 7.5]. In this text, the term "E value" is used as a measure of the primary energy consumption. The EPB requirements and recommendations concerning ventilation in residential dwellings are based largely upon the NBN D 50-001 standard governing ventilation [Ref. 7.6].

The minimum design flow rates for air supply, throughflow and exhaust are defined according to the type of room and the floor area (excluding WCs and open-plan kitchens).

Type of room	Surface area of the room	Air supply	Air throughflow: capacity (or free cross-section)	Air exhausted to the outside
Bedroom, study, playroom or hobby room (or equivalent)	Less than 7 m²	25 m³/h	25 m³/h (or 70 cm²)	
	Between 7 and 20 m²	3.6 m³/h m²		
	Over 20 m²	72 m³/h		
Living room, lounge, dining room (or equivalent)	Less than 21 m²	75 m³/h	25 m³/h (or 70 cm²)	
	Between 21 and 42 m²	3.6 m³/h m²		
	Over 42 m²	150 m³/h		
WC			25 m³/h (or 70 cm²)	25 m³/h
Kitchen (closed), bathroom, laundry area (or equivalent)	Less than 14 m²		Kitchen: 50 m³/h (or 140 cm²) Remaining rooms: 25 m³/h (or 70 cm²)	50 m³/h
	Between 14 and 21 m²			3.6 m³/h m²
	Over 21 m²			75 m³/h
Open-plan kitchen				75 m³/h

Table 5: Minimum design flow rates in accordance with the EPB regulation (NBN D 50-001)

For natural supply and exhaust vents and for intermediate airflow vents, the flow capacity for a pressure differential of 2 Pa must be at least equal to the minimum design flow rates listed in Table 5. The total design flow rate of natural supply air vents however must not exceed double the required minimum design flow rate for these rooms.

If the intermediate airflow vents take the form of gaps beneath doors, the total minimum cross-section of these gaps must be at least equal to the free cross-sections stated in the table above for the type of room in question. Where mechanical air supply or exhaust is employed, the minimum flow rates must be assured in all affected rooms for at least one fan setting (usually the highest).

For system D (mechanical supply and exhaust), it is strongly recommended that a system be implemented with identical design flow rates for supply and exhaust, particularly if the system employs heat recovery. A flow balance can be attained by mechanical recycling of air from certain rooms, increasing of the exhaust flow rate, or provision of supplementary air exhaust (for example in halls, corridors, etc.) with the necessary supplementary intermediate flow vents.

Besides requirements concerning the design of the system, the EPB regulation also sets out requirements concerning certain ventilation components. Depending upon the basic ventilation system selected (A, B, C, D), the following ventilation components are installed: natural supply vents (systems A and C), natural exhaust vents (systems B and D), supply and exhaust air vents, valves, ducts and HVAC units (mechanical systems B, C and D) and intermediate airflow vents.

Natural supply air vents

A natural supply air vent (system A or C) can be fitted within an exterior wall or integrated into a window (on the glass or on the frame) or a door in order to provide “dry areas” with the necessary supply of fresh air. Natural supply air vents are also used for the cross-ventilation of special areas such as lofts and cellars, and as supplementary supply air vents in “wet areas”, in order to prevent excessive partial vacuums.

Besides the minimum flow rate requirements [Table 5], the EPB regulation states additional requirements/recommendations, depending upon the Region concerned, for the natural supply air vents regarding their facility for adjustment, thermal comfort, protection against the ingress of vermin, water tightness, location in sloping roofs, etc. In the interests of energy savings (reduction of the E value) and enhanced comfort, self-regulating supply air vents (Class P3 or P4) are recommended. Such vents adjust the flow cross-section automatically according to the pressure differential, the temperature, the relative humidity, etc., in order to assure a constant air flow rate.

Other performance requirements found in the NBN D 50-001 ventilation standard [Ref. 7.6] concern the design safety, strength and rigidity; the ease of maintenance; the installation and maintenance regulations; cleanliness during installation; the material characteristics; the geometric characteristics; the facilities for control; and the operational service life.

Natural exhaust air ducts and vents

Natural exhaust air vents (systems A and B), by which stale air is discharged to “wet areas”, are often employed in (flat or sloping) roofs, and generally consist of a controllable vent on the inside, a ventilation duct, and a vent on the outside.

Besides the minimum design air flow rates [Table 5], the EPB regulation places a number of further requirements upon the facility for control, limitation of the air velocity (cross-section of the room), and the verticality and exit of the duct (above the roof). Recommendations in the EPB regulation and NBN D 50-001 also relate to the projection of ventilation ducts above the roof (at least 50 cm and as close as possible to the ridge), fitting of a hood, and the use of stiff, smooth piping and airtight ducts and fittings, etc. Multiple exhaust air ducts should preferably be connected by means of a shunt system. Exhaust air ducts must in addition be isolated at the level of unheated rooms, in order to prevent the risk of draught and condensation.

Supply air vents and exhaust air vents (mechanical ventilation)

Vents for supply air and exhaust air in mechanical ventilation systems (systems B, C and D) are generally fitted into an exterior wall or the roof. The sole requirement of the EPB in this respect is that the supply air vents be fitted such that they are able to supply outside air or air from an adjacent unheated room if the latter is connected to the outside environment via one or more natural supply air vents with the suitable design air flow rate [Table 5]. The location of supply air vents should be selected such that poor-quality air is not drawn in. Exhaust air vents (ventilation, cooker extractor hoods, etc.) and smoke flues should therefore preferably be located one storey higher (i.e. at an interval of at least 2 m), or better still in an outside wall facing in a different direction. All supply air vents should be located as far away as possible from busy roads, car parks, refuse disposal points, the ground, and vegetation. Sufficiently large supply air vents (air velocity < 2m/s), rain caps and insect mesh are recommended. In order to prevent blockage by snow, the air vents should ideally project sufficiently above the roof.

Intermediate airflow vents

An intermediate airflow vent through which air passes from “dry areas” to “wet areas”, possibly via an intermediate room, may be a vent in an interior wall or interior door, or even a gap beneath an interior door. Intermediate airflow vents should not be controllable or closable. Where use is made of “intermediate rooms”, the air must be able to follow an unbroken path. In some instances, intermediate airflow vents with the statutory minimum dimensions appear to be insufficient to allow an effective free flow of air. The result may be additional heat losses and/or inadequate air exchange. It is therefore appropriate, especially in areas with high air flow rate such as living rooms, for intermediate airflow vents to be installed with a greater flow rate capacity than that required by the legislation.

Valves, ducts, fans and HVAC units

Mechanical air supply systems (B and D) generally include an external air supply (in an exterior wall or the roof), a duct system, supply valves in "dry areas", and possibly filters, dampers, control valves and a preheating element. Preference should be given to Class F5 to F7 fine filters [Ref. 7.7].

Mechanical supply air systems (C and D) generally include exhaust air valves in “wet areas”, a duct system, an exhaust fan, an exhaust air vent (in the roof or an exterior wall), and possibly filters, dampers, control valves, etc.

A heat exchanger for heat recovery can be installed on systems with both mechanical supply and exhaust (system D). The ducts between the HVAC unit and the insulated volume must then be provided with additional insulation (see “Energy-related aspects”).

In order to limit pressure loss in the system and the corresponding increase in fan power consumption, the duct system should be kept as short, compact and straight as possible and should preferably consist of large, round-section piping manufactured from rigid materials with a smooth inner surface. Sufficient airtightness of the ducts should also be assured. In order to facilitate maintenance of the system, access points are recommended in the form of removable elements, tees or hatches in the duct system.

Energy-related aspects

The selection of the system and of certain components may have an influence upon other aspects of the EPB regulation, particularly calculation of the E value. Ventilation is always coupled with a certain power consumption. On the one hand, energy is needed in order to heat up or cool down the supply air (ventilation loss). This loss can be limited by measures such as demand-driven ventilation and heat recovery (balanced mechanical ventilation). On the other hand, energy is consumed in mechanical ventilation systems by fans. The power consumption of system D is then understandably higher than that for system A. Conversely, the thermal requirements are lowest for system D (with heat recovery) and highest for system B. Control of the air flow rates, powerful fans, heat recovery, etc. are different possibilities by which the power consumption of a building and thus its E value can be reduced.

Some components also have an influence upon the U values (heat transmission coefficients) of the walls of the building envelope and therefore the K value (global thermal insulation value). In order to limit the energy loss at the vents and also to prevent condensation, preference is given to vents with the lowest possible U values. Vents with a U value of ± 3 W/m² K are currently available. Supply air vents and exhaust air vents which penetrate the envelope of the building (mechanical ventilation) also result in additional heat loss. By means of detail adjustments, the cold bridge at this point can be limited and an airtight transition assured.

For an average dwelling equipped with ventilation system C and an average E value of 97, the energy losses from fans and ventilation constitute 25% of the E value, rising to as much as 50% for extremely well insulated and airtight buildings. Measures for limiting this energy consumption are therefore important. It should not be disregarded that the efficiency of the system for heating of the indoor air has an effect upon the power consumption for ventilation purposes (ventilation losses). A number of measures are discussed below for reduction of the energy consumption caused by ventilation.

Quality of execution

Monitoring of the ventilation flow rates guarantees that fresh air is supplied to the right point in the dwelling in the right quantity, and that at the same time high ventilation losses are avoided. For this to be achieved, the installation quality of the ventilation system is important. For a natural air supply (systems A and C), self-adjusting supply air vents are required. These prevent excessive ventilation, even during strong winds and major differences between the indoor and outdoor temperatures.

For a mechanical ventilation system, the ducts must be airtight and the supply and exhaust air valves adjusted correctly, with an air flow rate of between 100% and 120% of the minimum required design flow. Both aspects can be determined by measurement at delivery.

During calculation of the E value, consideration is given to the quality of execution of the ventilation system by introduction of the "m factor", which ranges from 1.5 (value in the absence of quality evidence) to 1 ("perfect" quality of execution) and assigned on the basis of supporting documents, which must be submitted.

Table 6 illustrates the criteria used for assignment of the m factor to the various basic ventilation systems. This shows that "perfect" quality of execution is possible only for type D systems.

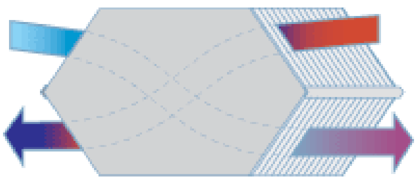
System	Self-adjusting RTO	Good duct airtightness	Appropriate adjustment	m factor
A	X	x		1.5 → 1.26
B		x	x	1.5 → 1.17
C	X	x	x	1.5 → 1.017
D		x	x	1.5 → 1.0

Table 6: Assignment of values for the quality of execution by the "m" factor in accordance with the EPB regulation

Power consumption of fans

In order for the power consumption of the fans employed in mechanical ventilation systems to be reduced, three parameters must be considered: the flow rate to be delivered; the pressure differential to be overcome in the ducts; and the efficiency of the fan/motor combination. It should be apparent that in the first instance, excessive ventilation must be avoided. Good design, airtight ducts, correct settings and demand-driven adjustment of the air flow rate contribute to this. Next, air circuits with low pressure losses must be selected. This includes air intakes, ducts, dampers, filters, heat exchangers, valves, and vents adjusted to the flow rate between the different rooms. In addition, the ducts must be designed and implemented with care, i.e. a compact system, ducts of adequate diameter, airtight ducts, etc. Finally, an energy-efficient fan must be selected. This means a fan adapted to the flow rate and pressure loss, preferably with a DC motor, speed adjustment for flow-rate control, and a wide control range (e.g. from 20% to 100% of maximum flow).

Heat recovery



In system D with balanced ventilation (supply and exhaust air flow rates in equilibrium), heat recovery rates of 50-80% can be achieved by the use of a heat exchanger which transfers heat from the exhaust air to the supply air. Countercurrent exchangers usually have a higher efficiency than crossflow exchangers.

In order to avoid heat loss and to reduce the risk of condensation, the ducts must be insulated. If the HVAC unit is located within the insulated volume, the ducts between the external environment and the HVAC unit must be insulated. If the HVAC unit is installed outside the insulated volume, the ducts between the insulated volume and the HVAC unit must be insulated.

Heat exchange can be switched off by means of a bypass mechanism if it is not required (spring/autumn, summer). Some systems are also capable of using the cooler interior air to cool the supply air at very high outdoor temperatures. In system C, heat from the exhaust air can be used by means of a heat pump (heat-pump boiler) to heat the (sanitary) water. Both measures have a positive impact on the calculated E value.

The table below indicates the extent (order of magnitude) to which the measure can reduce the E value and thus the power consumption for the ventilation system in question.

Measure	System A	System B	System C	System D
Self-adjusting RTO	0-5 pot		0-2 pot	
Airtightness of ducts	0-2 pot	0-5 pot	0-5 pot	0-5 pot
AC → DC fans		0-2 pot	0-2 pot	0-2 pot
True consumption of fans		0-5 pot	0-5 pot	0-5 pot
Adjustment of valves		0-5 pot	0-5 pot	0-5 pot
Heat recovery and flow-rate balancing				10-20 pot
Summer bypass (only with heat recovery)				0-2 pot

Table 7: Influence of energy-saving measures upon the E value for various ventilation systems

Comfort aspects

Thermal comfort

The thermal discomfort caused by cold air currents appears to be greatest in system B, thus making preheating necessary on occasions. Conversely, system D equipped with a heat recovery system provides the best thermal comfort. In order for the thermal comfort to be assured, the EPB regulation sets out a number of requirements/recommendations at installation component level. In order to prevent exposure to damp and to reduce the risk of break-ins, natural supply air vents should preferably be located at a height of 1.80 m above the finished floor level. If this requirement cannot be met, they should be located with a view to ensuring the swiftest possible mixing with the hot air by the radiators.

Acoustic comfort

Besides exerting a possible (negative) impact upon the thermal comfort of the residents, the various ventilation system components are also a major factor in the perceived acoustic comfort. Whereas in natural ventilation systems, the environmental noise can easily penetrate through the adjustable supply air vents (systems A and C), a real risk exists in mechanical ventilation systems (systems B, C and D) of noise exposure caused by the fan, flow noise and turbulence from valves, pipe bends and grilles. The greater risk of "cross talk" through the duct system (with mechanical ventilation), and increased sound transmission through the intermediate vents between the rooms, should also not be disregarded.

Outside wall sound insulation

For systems with natural air supply and/or exhaust, the EPB regulation recommends vents with integral soundproofing, in order for the risk of environmental noise exposure to be reduced and for compliance with the minimum requirements of NBN S 01-400-1 [Ref. 7.8] governing the acoustic criteria for residential buildings.

The orientation of the outer wall in which the adjustable supply and exhaust air vents are located, and also the vents' location within the outside wall, the form of installation in the cavity wall structure and their location within the inside wall, all have an influence upon the impact of outside noise upon the perceived acoustic comfort in dwellings with regard to the environmental noise. Judicious positioning of the supply or exhaust air vent, without impeding efficient air exchange, thus also means that overpressure zones, corners and edges of outside walls, and outside wall areas exposed to heavy rain, wind and noise should be avoided. In addition, vents with a horizontal access path should be preferred, i.e. recessed behind a gap in the outer cavity wall leaf; and overdimensioned grille areas and locations close to edges and corners within rooms should be avoided.

In order for the sound insulation requirements for the outside walls of living rooms, kitchens, studies and bedrooms to be satisfied in accordance with Belgian standard NBN S 01-400-1 [Ref. 7.8], acoustically damped vent grids or wall dampers are usually required. The purpose of the requirement for the outside wall (D_{Atr}) is the attainment of an optimum indoor noise level and is therefore a function of the noise exposure in the outside environment (L_A) and the number of outside walls enveloping the receiving room under consideration (m).

	Normaal akoestisch comfort	Verhoogd akoestisch comfort
Woonkamer, keuken, studeerruimte en slaapkamer	$D_{Atr} \geq L_A$ - 34 + m dB (1) en $D_{Atr} \geq$ 26 dB	$D_{Atr} \geq L_A$ - 30 + m dB (1) en $D_{Atr} \geq$ 30 dB
Slaapkamer	$D_{Atr} \geq$ 34 + m dB (1)(2)	

Table 8: Table of requirements from NBN S 01-400-1 concerning the minimum sound insulation of an outside wall

The outside noise level (L_A) is derived from a reference level (L_{Aref}) determined at a distance of 2 metres from the centre of the outside wall exposed to the highest noise level. According to the location of the building in relation to the major traffic routes, the relationship between L_A and L_{Aref} or a number of schematic drawings are indicated (Figure 49).

Klasse	Typebeschrijving	L_{Aref}
1	Veelal bij rustige, landelijk wegen, rustige verkaveling met lokaal verkeer of in stadstraten met lokaal, beperkt verkeer	60 dB
2	Stadstraten met normaal verkeer op asfalt, 1 rijvak per rijrichting	65 dB
3	Druk, traagrijdend verkeer	70 dB
4	Veelal bij stadstraten met zeer intens verkeer (bvb. Beliardstraat te Brussel), bij wegen met betonnen wegdek en met druk verkeer, langs nationale wegen, bij invalswegen naar grotere steden en bij verbindingswegen met regelmatig zwaar verkeer naar industrieterreinen.	≥77 dB

Table 9: Table of guide values for L_{Aref} in the described area types (NBN S 01-400-1)

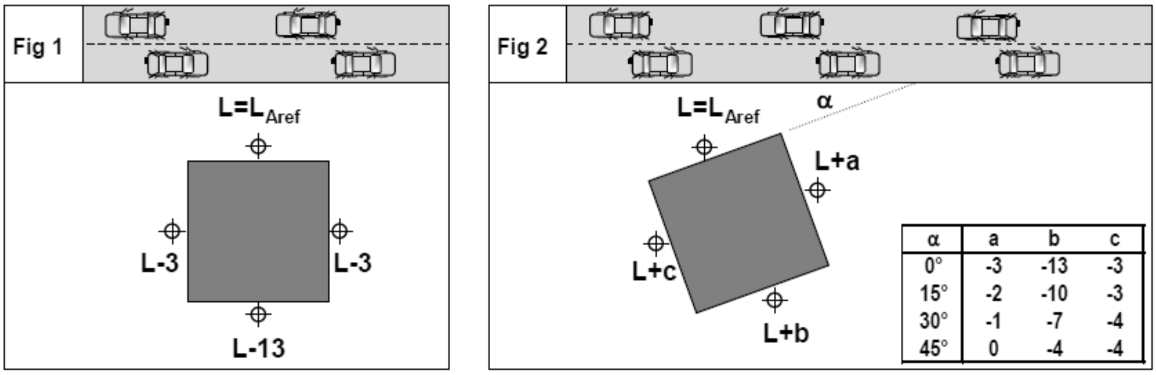


Figure 49: Schematic diagrams determining the relationship between L_A and L_{Aref} (from NBN S 01-400-1)

The default requirement for vents is thus derived from the requirement for the outside wall area (outside noise + number of outside walls), the number of vents in the wall(s), the volume of the wall behind them, and the total area of the "weak" outside wall elements. The relationship between the acoustic performance of the outside wall and the performance of the outside wall elements is based upon the analysis method described in European standard EN 12354-3 [Ref. 7.9].

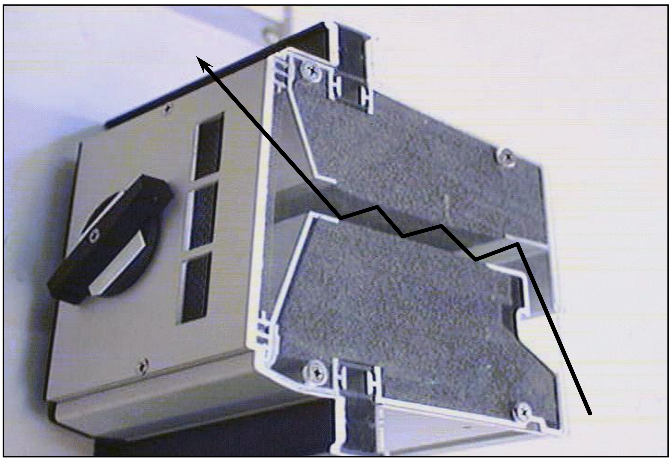
Eis voor de akoestische prestaties van gevelelementen (met inbegrip van de aansluitingsdetails met een aangrenzend gevelelement) die deel uitmaken van een gevelvlak van een woonkamer, keuken, studeerruimte en slaapkamer	
Alle gevelelementen uitgezonderd ventilatieroosters	$R_{Atr} \geq D_{Atr} + 3 + 10lg[3(S_{netto} + 5n)/V]$ [dB]
Ventilatieroosters indien aanwezig	$D_{neAtr} \geq R_{Atr} + 3$ [dB]

Table 10: Default values for the minimum sound insulation of outside wall elements (from NBN S 01-400-1)

The natural vents in residential buildings are frequently smaller than 1 m² and are therefore characterized acoustically by $D_{ne,w}(_{C;Ctr})$. The value of this quantity describes the sound insulation of a wall of 10 m² with very high sound insulation on which the vent in question is fitted.

Calculation of the minimum necessary D_{neAtr} ($=D_{ne,w+Ctr}$) for the vents in the outside wall in accordance with the method described in the Belgian standard [Ref. 7.8] or the detailed European analysis method [Ref. 7.9] suggests that performances of 30 dB may easily be necessary. Consequently, a standard vent grille that has not been acoustically improved will in most cases be unable to satisfy the requirements of the Belgian standard for outer wall sound insulation. For acoustically improved vent grilles, a performance of up to 50 dB is feasible. At extremely high environmental noise levels and/or with large apertures in the outside wall, mechanical ventilation may be the only solution for satisfactory comfort with respect to external noise.

Vents with enhanced acoustic resistance possess sound-absorbent material along which air is supplied and exhausted, and the sound waves which occur are damped by friction. It goes without saying that the vent grille itself should have a sufficiently high acoustic insulation value; if not, its sound-absorbing capacity will be of no benefit. Increasing the contact duration and surface area results in the sound waves being absorbed more efficiently. This is possible by the creation of a long, circuitous route through the sound-absorbent material. Acoustically damped vents directly in outside walls (wall dampers) rather than over windows or frames thus also have the advantage that the entire wall thickness can be exploited to create this path. By provision of an extra-thick absorbing layer in the damper, the performance is enhanced, above all in the low-frequency range. For the creation of efficient dampers, substantially greater installation heights and depths are then also required than those for undamped vents with the same ventilation flow rate. By judicious choice of geometry, absorptive capacity of the materials used and length of the damper, a compromise must be found between damping capacity, pressure loss and aesthetics.



With regard to the materials employed, the fire resistance, resistance to unravelling, porosity, wrinkling, cost, etc. must be considered in addition to the absorbency. Mineral wool or open-cell foams may be considered for this application.

Noise emanating from buildings services

Where mechanical air supply and/or air exhaust is employed (systems B, C and D), the risk of noise exposure is significant owing to the fan and to the flow and turbulence in the duct system. In order to satisfy the criteria stated in NBN S 01-400-1 [Ref. 7.8] regarding noise emanating from buildings services, a number of recommendations must be observed.

Beperking van de overschrijding $L_{AS,max,T}$ - $L_{Aeq,T}$		
Meetruimte	**Normaal akoestisch comfort**	**Verhoogd akoestisch comfort**
Woonkamer, studeerruimte	≤ 6 dB	≤ 3 dB
Slaapkamer	≤ 3 dB	≤ 3 dB
Er wordt geen rekening gehouden met de beperking van de overschrijding wanneer deze waarde voor ($L_{AS,max,T}$ – k) niet hoger is dan:		
	Normaal akoestisch comfort	**Verhoogd akoestisch comfort**
Woonkamer, studeerruimte	33 dB	30 dB
Slaapkamer	30 dB	28 dB

Table 11: Maximum excess noise for buildings services installations in residential buildings in accordance with NBN S 01-400-1:2008

		Normaal akoestisch comfort $L_{Ainstal,nT}$	**Verhoogd akoestisch comfort** $L_{Ainstal,nT}$
Badkamer / WC	Mechanische ventilatie	≤ 35 dB	≤ 30 dB
	Sanitaire apparaten	≤ 65 dB	≤ 60 dB
Keuken	Mechanische ventilatie	≤ 35 dB	≤ 30 dB
	Dampkap	≤ 60 dB	≤ 40 dB
Woonkamer, studeerruimte	Mechanische ventilatie	≤ 30 dB	≤ 27 dB
Slaapkamer	Mechanische ventilatie	≤ 27 dB	≤ 25 dB
Technische ruimten met installaties voor minder dan 10 woningen		≤ 75 dB	≤ 75 dB
Technische ruimten met installaties voor meer dan 10 woningen		≤ 85 dB	≤ 85 dB

Table 12: Maximum sound levels for buildings services in residential buildings (NBN S 01-400-1:2008)

In order to prevent the spread of noise originating from the fan, a silent fan or HVAC unit should ideally be selected and preferably installed in a buildings services room, storage room, laundry room, cellar or similar. The fan or HVAC unit should be fitted to the building structure with vibration damping (e.g. silent block) and connected to the ducts with a very short sleeve of flexible material. The flow rates should be adjusted to the actual needs, and adequate sound insulation is necessary for the structure separating the room in which the fan or HVAC unit is installed (buildings services room) and the adjoining living rooms or bedrooms. Properly dimensioned dampers can be installed between the valves and the fan or HVAC unit, in both the supply and exhaust air ducts. Installation of a damper is recommended immediately downstream of the fan outside the buildings services room. Additional dampers can be fitted if necessary, for example immediately upstream of the controls.

In order to limit the generation of noise in the duct system, the air velocity should in the first instance be limited to a maximum of between 1.5 and 2 m/s in the end sections immediately upstream of the supply or exhaust valves. Preference should be given to valves with the lowest possible noise generation (manufacturers' data should be requested). Valves with integral noise damping can prevent the risk of crosstalk between rooms through the duct system. Unnecessary bends, constrictions, flaps, etc. should be avoided, particularly immediately upstream of the valves. Valves should preferably not be fitted in the corner/ceiling or corner/floor transition of rooms. A plenum space in the suspended ceiling can be used to provide additional noise damping immediately before the opening into the room. Noisy ventilation ducts in noise-sensitive rooms should be fitted in acoustically insulated shrouding or in an engineering plenum space (ceiling or floor).

Internal sound transmission

The presence of intermediate vents in interior doors or walls considerably compromises the sound insulation between adjacent interior rooms. The criteria for minimum airborne sound insulation between rooms within a dwelling in accordance with NBN S 01-400-1 [Ref. 7.8] can thus be jeopardized.

ZENDRUIMTE binnen de woning	ONTVANGSTRUIMTE binnen de woning	Normaal akoestisch comfort	Verhoogd akoestisch comfort
Slaapkamer, keuken, woonkamer en badkamer (die niet alleen toebehoort aan de slaapkamer/ontvangstruimte)	Slaapkamer, studeerruimte	$D_{nT,w} \geq 35$ dB	$D_{nT,w} \geq 43$ dB

Table 13: Requirements for the airborne sound insulation between rooms within a dwelling (NBN S 01-400-1:2008)

For reasons of acoustic comfort inside the dwelling it is therefore advisable for bedrooms, kitchens, living rooms or bathrooms not to be connected directly with another bedroom or study by a door or a wall vent. The flow of supply air from bedrooms or studies to kitchens or bathrooms is therefore best routed through an intermediate room. In order for the sound transmission between these rooms to be limited and to satisfy the criterion for normal acoustic comfort, $D_{nT,w} \geq 35$ dB, intermediate vents with integrated sound dampers are recommended in addition. The length of the air path through this damper is crucial for the efficiency of sound damping: the longer the path, the greater the damping. In some cases, superior sound damping is possible with an intermediate vent in a wall (longer path) rather than in a door. Manufacturers usually state the noise damping values of their products, thereby permitting comparison. Intermediate vents in the form of a gap below the door should always be avoided wherever noise damping is desired.

Choice of systems

The advantage of mechanical systems for the inflow or evacuation of air is the assurance of the real flow. Effectively, if the mechanical evacuation is adjusted to a flow of 150 m³/h, then the air entryways within the residence will balance out based on their ability to provide corresponding air inflows. The downside of these mechanical systems is a little additional energy consumption and a slight operating noise.

For new constructions, the systems can be designed and integrated into the building plans from the very beginning of the project. Selecting a single option from among the specified groups is thus easily conceivable. In acoustic renovation, as in all insulation works, the project designer must submit to the constraints of the habitation. Therefore, while the selection of a single system may be preferable, a mixture of systems may be unavoidable. This is especially important because the acoustic performances of multiple ventilation systems are far from equal. Thus, the acoustic insulation requirements of a façade are a determining factor in the choice of ventilation system. The most-often implemented ventilation systems for acoustic renovation and for new builds are systems C and D.

Acoustic performances of the various systems

There is a great diversity in ventilation devices, and even more in installation configurations. The purpose of the following paragraphs is therefore not to provide an inventory of all the existing elements, but rather to establish a summary of the various possibilities for ventilation technologies, and their acoustic performances. The complete test report, as well as the descriptive schemas, can be found in annex.

Natural air inflow through a wall opening

The systems tested were based on a simple wall opening of 125 mm in diameter. The inside of the wall opening was lined with a 125 mm rigid galvanised steel sheath. The table below gives the insulation values measured in the laboratory.

Description	Acoustic insulation $D_{ne,w}$ (C;Ctr) [dB]
Steel Pipe	29(0;0)
Steel Pipe with sleeve	44(-1;-2)
Steel Pipe with sleeve + wide open vent	48(-1;-4)
Steel Pipe with sleeve + slightly open vent	54(-1;-5)

An acoustic sleeve made up of a sheet of open-cell foam remarkably improves insulation levels, with a gain of about 13 dB. It appears that the interior vent opening has a non-negligible impact. Depending on the configuration selected and the numeric values, these types of systems could be utilised for a façade insulation up to $D_{2m,ls,nT}$ (C;Ctr) ~ 41 (-1;-5) dB.

Air inflow or evacuation by cabinet sleeve

This solution adds variable lengths and encasing elements to the wall silencer described in the preceding paragraph. These are acoustic sheath elements that can be wither bare or encased in a steel sheath or an MDF box. The installation of a motorised ventilator inside these systems was not tested, but this couldn't help but benefit the overall insulation, à priori, by a margin of several decibels.

To obtain a mechanical air inflow, the motorised extraction ventilator can be inserted inversely, in such as way that it insufflates the air into the room, instead of outside.

During the tests, the entire sheath or cabinet was exposed to noise. If the ventilation system is placed in a room (acoustically insulated or not) the true value of the insulation will be found to be much higher. Noise therefore enters principally or even exclusively from the far end of the conduit. The table below gives the insulation values measured in the laboratory for the configurations without a rigid box.

Description	Acoustic insulation $D_{ne,w}$ (C;Ctr) [dB]
Pipe + 3 m sheath	42(-1;-2)
Pipe + sleeve + 3 m sheath	52(-1;-4)

The acoustic sheath again offers a gain of about 10 dB.

The table below gives the insulation values measured in the laboratory for the configurations without an absorbent sheath.

Description	Acoustic insulation $D_{ne,w}$ (C;Ctr) [dB]
Pipe + 3 m metal conduit	52(-1;-3)
Pipe + 18 mm MDF box	46(0;0)

Given that the sheath was exposed to noise among its full length, it appears that the configurations with rigid sheathes provide the best results. The table below gives the insulation values measured in the laboratory for the configurations combining an absorbent sheath and rigid box.

Description	Acoustic insulation $D_{ne,w}$ (C;Ctr) [dB]
Pipe + 1m sheath in a metal conduit	43(-1;-4)
Pipe + 3m sheath in a metal conduit	58(-2;-7)
Pipe with sleeve + 3m sheath in a metal conduit	63(-2;-6)
Pipe+ 3 m sheath in an MDF box	53(-2;-6)

The combination of the absorbent sheathes and rigid boxes makes it possible to obtain values that are completely compatible with the highest insulation levels for the façade that may be required in zones located close to airports (in Wallonia, level difference $D_{2m,ls,n,T}$ +Ctr = 42 dB). Depending on the configuration selected and the numeric values this type of system could be used for façade insulation of up to $D_{2m,ls,n,T}$ (C;Ctr) ~ 50 (-2;-6).

Air inflow by vertical cabinet

This solution adds an MDF box along the length of the wall to the wall silencer described above. This box can be covered in a rock wool-type absorbent material or can contain an acoustic sheath to improve the insulation of the device. Caps can also be installed. The table below gives the insulation values measured in the laboratory. The complete test report, as well as the descriptive schemas, can be found in annex.

Description	Acoustic insulation $D_{ne,w}$ (C;Ctr) [dB]
Empty MDF box + open vent	45(-1;-2)
Empty MDF box + sleeve + open vent	58(-2;-6)
MDF box + sheath + sleeve + open vent	62(-2;-6)
MDF box + rock wool + sleeve + open vent	67(-2;-6)

In this configuration, the acoustic sleeve offers a gain of 13 dB to 11 dB depending on the weights. The installation of the absorbent sheath, and especially the rock wool, also increases the insulation level of this system. Considering the "stable" performance of the sleeve, it is possible to estimate the acoustic insulation values for these systems without the sleeve, by subtracting 10 dB from the measured results. Depending on the configuration selected and the numeric values, this type of system could be utilised for façade insulation of up to $D_{2m,ls,n,T}$ (C;Ctr) ~ 57 (-2;-6) dB.

Air inflow by ventilation grills

The simplest technique to implement is undoubtedly that of ventilation grills in the upper part of the building frame. While certain window typologies might restrict their placement, they permit a ventilation of the interior rooms without taking up any interior volume. These grills are often made of aluminium and plastic, and are attached on the upper transom of window or door frame. They usually have a grille on their exterior face and a valve with adjustable opening on the interior side. The powerful acoustic models have an interior module containing melamine foam-type noise-absorbing material. The air passage can also be extended by using a baffle. The insulation values of these types of systems measured in the laboratory can vary between $D_{ne,w}$ (C;Ctr) = 39 (0;-2) and $D_{ne,w}$ (C;Ctr) = 49 (-2;-5). Certain models with greater interior thickness obtain even better performance values: $D_{ne,w}$ (C;Ctr) = 56 (-2;-6). Depending on the configuration selected and the numeric values, these types of systems could be used for façade insulation of up to $D_{2m,ls,n,T}$ (C;Ctr) ~ 46(-2;-6).

Mechanical air inflow through the wall

Mechanical air inflow through the wall is not a system currently used much. It usually involves a local auxiliary system, and is not really meant to be installed in a systematic manner. This system can comprise a compact box fitted with a centrifugal ventilator. The interior of the box can be treated acoustically: specifically, with noise-absorbing material like melamine foam. Before the main box is installed in the residence, the exterior wall must be drilled. The resulting air duct is then connected or simply put in direct contact with the back face of the main box. In this way, the air is aspirated through the duct in order to be insufflated inside the residence. Installing an absorbent acoustic sleeve in the air duct can increase the system's airborne noise insulation.

The insulation of this type of system, measured in the laboratory, can reach $D_{ne,w}$ (C;Ctr) = 50 (-2;-4) dB. Depending on the configuration selected and the numeric values, this types of system could be utilised for façade insulation of up to $D_{2m,ls,n,T}$ (C;Ctr) ~ 44 (-2;-4) dB.

Group D

This is the most efficient ventilation system, as much in terms of energy consumption as from the acoustic point of view. For optimal operation of the system, the residence must paradoxically be as tightly sealed as possible. In effect, the air flows at the entries and exits are managed globally by an electronic system, so leaks have a tendency to disrupt the balance. For this reason, in addition to the cost, this system is primarily utilised for new builds or residences in which the great majority of the principle rooms are soundproofed.

A large central box centralises the entering and exiting air flows, assuring thermal exchanges. A network of ducts starting from this central box connects the various sites within the residence. The connections with the outside are limited to a single air inflow duct and a single air extraction duct. Taking as an assumption that the noise entry from the two principle ducts is negligible, the acoustic performance can be evaluated thanks to the tests summarised in the table below.

Description	Acoustic insulation $D_{ne,w}$ (C;Ctr) [dB]
Pipe with sleeve + 3 m sealed duct	53(-1;-4)
Pipe + 3 m duct in sealed MDF box	61(-2;-4)
Pipe with sleeve + 3 m duct in sealed MDF box	71(-2;-6)
Pipe + 3m duct in a sealed metal conduit	69(-2;-6)

Depending on the configuration selected and the numeric values, this type of system could be utilised for façade insulation of up to $D_{2m,ls,n,T}$ (C;Ctr) ~ 60 (-2;-6) dB.

Regarding this technique, the insulation is only limited by the insulation of the rigid box utilised. In order to further increase the insulation values, thicker and thus more high-performance boxes can be utilised.

7. E. CONCLUSION

Whether the project relates to an acoustic renovation or a new build, acoustic insulation cannot be developed without a corresponding development of the ventilation. And yet, at first glance these two necessities seem strongly contradictory. On the one hand, there is a need to seal the building as much as possible, by suppressing all leaks and cracks. On the other hand, there is a corresponding need to let in fresh air, and evacuate used air in all of the living spaces. But ultimately, the laboratory tests carried out on the ventilation devices, whether industrial or artisanal, as well as the feedback from actual experiences on high-level soundproofing worksites near airports, show that accessible, efficient and easily applicable technical solutions do exist on the market.

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