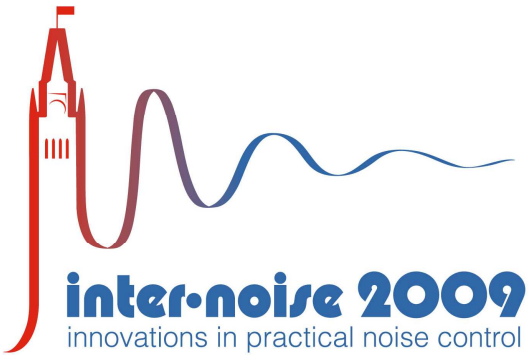

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Design of light weight constructions - risks and opportunities

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ABSTRACT

Still, it is advantageous to use heavy weight solutions prior to light weight structures in multi storey residential premises. This is natural since the risk exposure then is far less, caused by some important factors; Current ISO evaluation result in too many unsuitable light weight constructions; Heavy weight buildings prevent annoying low frequency structure borne noise and vibration; Lack of prediction models for light weight structures. To make the future light weight industry more competitive in such projects it is important to overcome the problems connected to these topics. Single number ratings must become subjectively equal independently of structural characteristics and regulations should include the impact of vibrations. Prediction models have to be developed in order to decrease the early stage risks in topical projects and to enable quick and correct anticipation of structural changes. Furthermore, sensitive details typical for light weight structures, i.e. flanking transmission reducing inter layers, has to be carefully designed. If these topics are not seriously taken into consideration there is a risk that the potential market share growth of multi-storey residential buildings with lightweight structures will diminish. An analysis describing future needs in detail, funded by VINNOVA in Sweden, was completed recently.

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1. INTRODUCTION

Regulations regarding sound insulation between dwellings are an area which needs a radical review too meet new modern building technique. Within a housing unit, i.e. noise from neighbours, there are a number of different noise sources which were not present some decades ago. However, this is only one part, the most serious failure in modern regulations is that it is possible to build very light constructions, experienced as subjectively unacceptable, and still fulfil not only minimum requirements [1] but also high sound classes in classification standards, i.e. SS 25267 [2], concerning impact sound insulation and vibrations. Light weight constructions may easily turn into motion through walking people, jumping children or rotating machines. Current regulations and standards are transparent to these annoying motions and hence, modern light weight building systems will be considered unfair with regard to its subjective experience. In the long run this will be in favour for the traditional heavy weight building industry, in case this is not taken seriously. Thus, the demand of modern light weight, highly prefabricated building systems, for multi storey residential premises might diminish. This would be a development which no one will experience, at least not in the Nordic countries, since the light weight building industry represents a completely new positive way of building multi storey residential buildings. These light weight production methods could be a success factor for the future building industry, in case sound insulation requirements correspond to expectation. Furthermore, it is environmentally attractive to use light weight structures, in particular wood.

Property developer who will develop new land area for multi storey residential housing blocks often has the ambition to fulfil sound class B according to SS 25267 [2]. The contractor commissioned to erect the buildings always tries to find a building system which will be “the best choice for client” in terms of quality, flexibility and of course the price. As long as the system fulfil the requirements specified by the property developer it might become an option. It could be a heavy weight system or a light weight system. The light weight systems become more and more interesting and competitive due to its highly prefabricated level and fast erection on site. Furthermore, it is easy to transport modules or elements to low cost, which imply new possibilities to import foreign systems increasing the competition between manufacturers.

Many light weight building systems on the market today are developed in order to meet high sound comfort, since it is important to become competitive with the traditional concrete industry in terms of sound insulation. This implies that the sound quality often is far better than specified in the building regulations [1]. However, there is a huge spread in quality and if applying nothing but current acoustic requirements as a design criteria, it is possible to build multi-storey houses in light weight material which will easily fulfil the general advice in terms of objective minimum requirements or even higher sound classes but still not acceptable in terms of subjective experience.

2. LIGHT WEIGHT STRUCTURES – RISKS

In Sweden more than 15 % of all multi storey housing residential buildings are erected using light weight structures. This figure increases constantly, in particular these days since the global economical crisis forces the building industry to find new, faster and cost effective building methods in order to supply the market with new residential premises.

A. Requirements

The building code in Sweden and in many other countries was developed when light weight structures were no option for multi storey residential buildings. Thus requirements are adapted to

heavy weight structural behaviour, i.e. current single number evaluation presuppose structures which actually have very good low frequency sound insulation and not sensitive to vibrations, at least not to vibrations which come up from normal household activities. Light weight structures often exhibit poor low frequency behaviour and if using single numbers without ISO spectrum adaptation terms[4,5] there is no requirements at all below 100 Hz, see figure 1. A few countries have extended the sound insulation requirements by using the ISO spectrum adaptation terms from 50 Hz. However, still most European countries are using the "old" frequency range 100-3150 Hz [3]. As new light weight building techniques are growing and enter the markets more frequently throughout Europe these figures have to be replaced fairly quickly, at least for residential premises where low frequency protection are of high importance. The requirements should direct the building industry, at least in those cases where it is obvious that a failure might have very serious consequences. It is too high costs and too much risk connected to failure in this case.

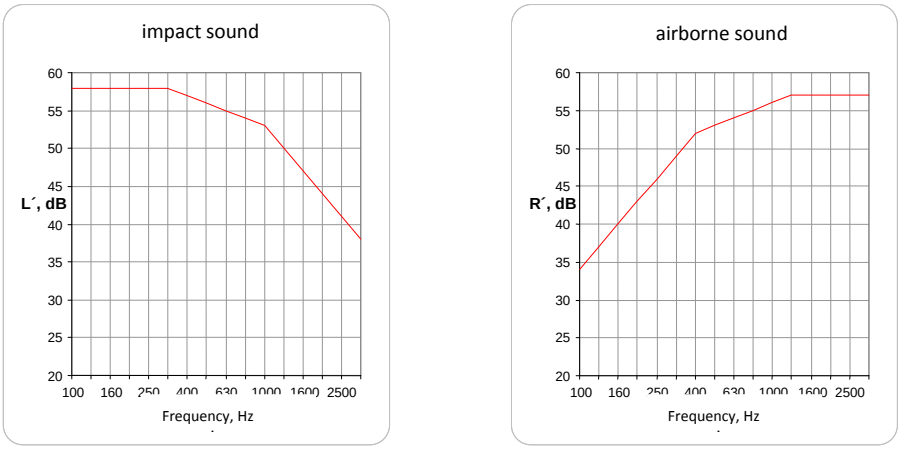

Figure 1: Evaluation curve shapes for impact sound level ($L'_{n,w}$ and $L'_{nT,w}$) and airborne sound insulation (R'_w och $D_{nT,w}$) according to ISO 717 [4,5]. These single numbers are still valid in many countries even though spectrum adaptation terms might be added in current regulations and even though completely new building structures becomes more and more frequent. Regulations should promote the building industry to develop its new constructions in the right directions instead of using old evaluation principles.

When the Swedish building regulations were revised in 1994 it comprised a dramatic change, not regarding its sound insulation requirements but instead some other very big changes. Wooden structures could be an option in multi storey buildings. Less severe fire requirements led to a new era which of course has been very interesting in many cases. Some research projects were initialized in order to develop wooden building technique. In this development certain sound insulation criteria were established since all parties involved were very aware of the acoustical problems and the risks connected to a failure [7]. Hence, the requirements were far higher than prevailing minimum requirements:

$$L_S \leq 62 \quad \text{dB} \tag{1}$$

$$L'_{n,w} \leq 53 \quad \text{dB} \tag{2}$$

$$f_R \leq 50 \quad \text{Hz} \tag{3}$$

where

$$f_R = 50 \times \left\{ \frac{\left(\left(1/m_1 \right) + \left(1/m_2 \right) \right)}{d} \right\}^{\frac{1}{2}} \text{ Hz} \quad (4)$$

where d is the cavity depth in m of the floor and m_1 and m_2 are the weight in kg/m^2 for the plate surfaces. The latter requirement was stated in order to secure proper airborne sound insulation. If instead using ISO 717 and applying $C_{\text{I,50-2500}}$ adaptation term the corresponding requirement to *eq*. (1) should be [6]

$$L'_{n,w} + C_{I,50-2500} \leq 56 \quad \text{dB} \quad (5)$$

which (in addition to $L'_{n,w} \leq 56$ dB) was adopted as minimum requirement in Sweden 1999.

These "pioneer" projects aimed to show that it was possible to build high sound quality with light weight structures. The results showed that it was actually possible if certain acoustical measures were undertaken. However, still 15 years later the requirements in most European countries are not adapted to modern structures and it is most likely that the willingness to build multi storey residential buildings with requirements far higher than the minimum requirements will decrease as the market grows and the costs have to be competitive to any other structure. Many new systems will be developed in order to meet minimum requirements or perhaps higher classes but still evaluated with single numbers from history and non existing vibration requirements. Not only the authorities in each country but also the light weight system manufacturer, have to take this seriously, since an increased market share will be interesting for new market operators. Operators that of course still fulfil the requirements, but perhaps not very interested to develop "over class" and expensive systems. And naturally, they presuppose that the requirements are acceptable for any building system. Consequently, there is a risk that the light weight structural system competitiveness will diminish compared to heavy weight systems.

B. Prediction models

The lack of acoustic prediction models might restrain the use and development of light weight structures. Masonite Beams has developed a system called MFB comprising components developed to obtain high sound insulation characteristics when compounded to a building. Theoretical analysis and extensive acoustic tests are performed, showing that the MFB-system has remarkably good sound insulation characteristics [10]. The system is also developed to obtain flexibility and adaptation of acoustic characteristics to various markets. However, the lack of prediction models regarding vibrations and sound insulation for light weight systems is a disadvantage in comparison to the opportunities for more traditional heavy weight systems.

C. Built-in material

Light weight structural systems are complex. In order to work properly many systems are equipped with elastic layers to reduce flanking transmission. These elastic layers might be sensitive to various loading but also to its behaviour over time. Normally it is necessary to use material with various characteristics on different floor levels and between different modules, depending on load. According to the Swedish building regulations [1] material built-in to a building structure must have well known characteristics in case those are important in order to

fulfil the essential requirements. A general advice specifies that material characteristics for essential products built-in the building should be specified. The elastic layers between elements are typical products that should be considered carefully, figure 2. The immediate behavior depending on loading on different floor levels and the long term behavior must be secured. If not, sound insulation might vary for different floor levels and there is a risk that it might deteriorate over time. Furthermore it might cause uncontrolled damage due to subsidence.

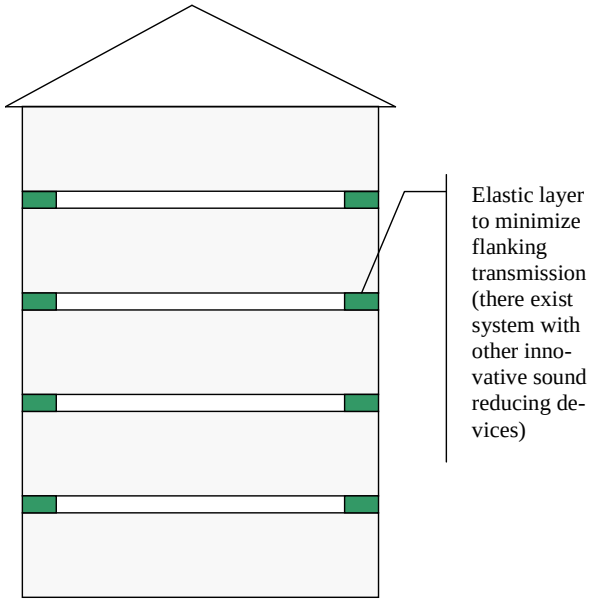

Figure 2: Elastic layers have to be designed in order to fulfil requirements in the Building code i.e. "Building material and building products which are used must have well known characteristics when their behaviour are of significance for the buildings ability to fulfil the requirements and the general advice" (BFS 2006:12) [1].

3. LIGHT WEIGHT INDUSTRY – OPPORTUNITIES

In case the risk factors are considered the light weight building industry has a unique chance to increase their market share at present, due to its highly industrialized way of producing and erecting multi-storey residential premises. Instantly, it is even more interesting to many building contractors since the global crises make them all anxious in finding alternatives to traditional building technique in order to cut prices and to shorten the time for erection on site.

A. Adaptation of light weight system

Modern light weight systems aimed for use in multi storey residential buildings could be:

- light weight beams system in steel
- building system in wood, either volume elements or plane cassette elements
- combinations of light weight and heavy weight material
- other new modern light weight constructions which might be developed in a modern society

Manufacturer of these systems have a unique chance to adopt new technique and to propose usage of their systems on projects where the systems could be highly competitive. However, in

order to promote new techniques to be applied where they appear at its best there are need for more detailed description of target values for various applications. This requires research to raise the knowledge of experienced sound insulation in various structures, various surroundings and not least various types of living accommodations. Hence, apart from a more equal evaluation independently of structural material for "normal residential premises" (see previous chapter), i.e family premises with parents and children, it would be advantageous for the modern building industry and for society to develop and adopt design criteria for other typical residential premises, i.e.

- Student residential premises
- Premises for elderly people
- Premises for families with grown up children
- Premises for occasional living

Furthermore, single handed households increases amongst those living in multi-storey buildings. Inhabitant way to live their lives has changed a lot over the decades passed since the main outline of current regulations was established. Therefore, it would also be of interest to study expected future living behaviour since this will affect the risk of noise exposure between dwellings.

B. Light weight systems and industrial development

The light weight industry definitely has a lead compared to heavy weight industry with regard to effective processes. MFB (Masonite Flexible Building System) is an example of a Swedish light weight system based on plane cassette elements in wood. The system is developed in order to be highly prefabricated using innovative joint connections to prevent flanking transmission and installations integrated in the system [10]. This implies a fast and effective assembly of the cassettes on-site. Traditional on-site production process has a number of disadvantages compared to industrialised plant production, such as

- reduced possibilities for control and measurements regarding output and quality (e.g. air tightness in components)
- slower and more expensive production, i.e. logistical problems
- exposure for weather conditions
- lack of routines for experience feedback

The prefabricated process, involves a more cost efficient, controlled and efficient residential building production, and when fully developed it imply high quality multi storey buildings to low costs. This stage in the process might be reached when the entire process from design to a complete building is clear, using benefits from cooperation in the entire "value chain". This is an obvious development trend in the Swedish building industry, and the light weight industry has a lead compared to the heavy weight industry in the ongoing (partly governmental supported) development of an industrialised construction process. As a specific example, the MFB-system, is developed and used in a cooperation group MICC – MFB Industrialised Constructive Cooperation. The group consists of various competences such as Architect, construction design expert, acoustic expert, component and plane cassette production manufacturer, weather protection supplier and contract companies. All participants have great knowledge of the MFB-

system (both benefits and limitations) which involve synergetic future effects both regarding quality and cost reduction. The process is described in figure 3.

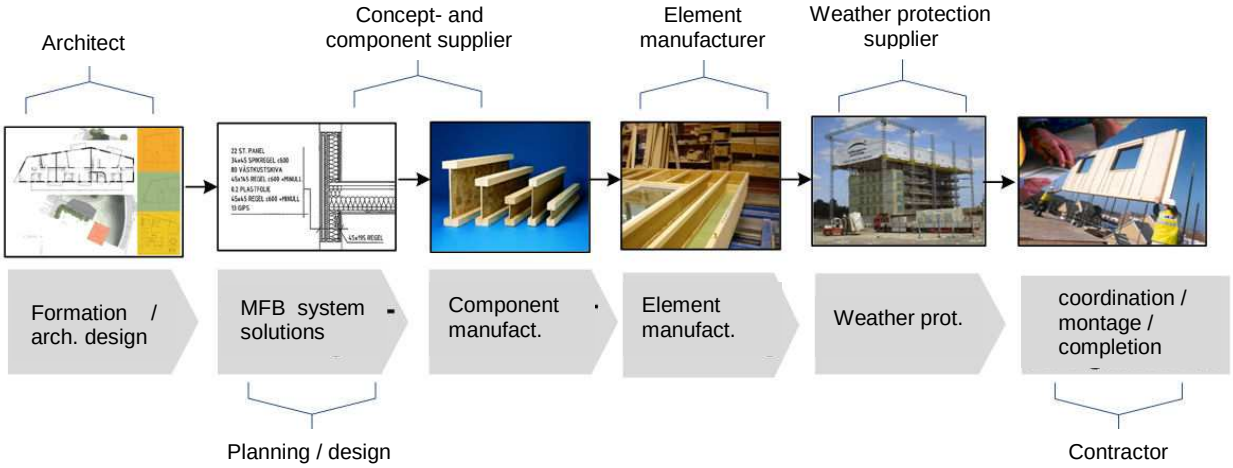

Figure 3: MICC process aimed to secure a delivery of light weight building systems for multi storey residential buildings with high quality predicted in advance. This involves high acoustic quality adapted to current demands from client.

Light weight systems, in particular wooden based systems such as MFB, have characteristics that make them suitable for prefabrication and industrialisation. Wood has a high manufacturability, and despite possible humidity dependent movements in the material, it is relatively easy to obtain high tolerances in the factory production, which again lead to an efficient production on-site. From a more product specific point of view, light weight building systems show opportunities related to transportation of prefabricated components and thus, high competitiveness for new distant markets (future export possibilities). The light systems facilitate additional storeys on existing buildings, in general foundation work is reduced, and it is advantageous to use the light systems when poor ground conditions are present.

4. DISCUSSION

In order to promote the light weight industry to expand its activity within multi storey residential buildings, acoustic target values should be in focus. Furthermore, they need to find a design tool for vibrations and requirements connected to this topic. In the beginning of the light weight industrial development of multi storey residential premises it was obvious that one of the main technical issues was acoustics, sound insulation structural behaviour. Stability and fire resistance of course, but acoustics was one very important technical issue amongst others. Still, 2009, many light weight systems on the market are quite good with regard to its sound insulation. Nevertheless, their acoustical behaviour compared to heavy structures is not enough investigated, sound classes are not experienced equally independently of the building structure. As the market share for light weight building systems increases in Europe the authorities need new tools and research support in order to be able to revise and harmonize future regulations. And it bustle, in particular since

- ISO 717 revision are already ongoing
- The development of new building system goes fast since the building industry is in big need to lower their costs

- trade with foreign light weight systems increase

Within this important area there has been some minor research work during years. Some interesting work within vibration has been carried out [8,9]. New evaluation curve shapes for impact sound have been suggested (valid for "normal" residential premises) which are partly included in ISO 717, see figure 4. Nevertheless, as an acoustician it´s amazing that the transition from very traditional heavy weight building technique to light weight building technique and at the same time new habits with regard to family compositions etc., requiring entirely different evaluation principles, has not caused more activity regarding research and building regulation development. In order to establish future criteria for various buildings a much more radical and broad scientific research programme is needed.

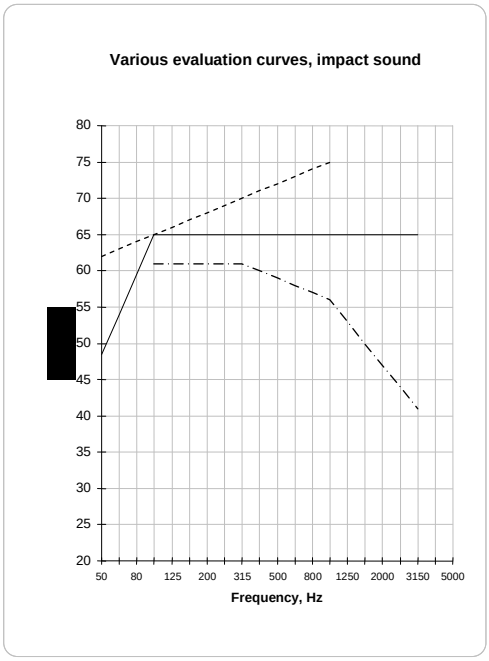

Figure 4: Evaluation curve shapes developed during different periods. -·-·-: ISO 717; - - - - -: Bodlund 1985 and ——— : Hagberg 2005. It is obvious that new building technique requires new evaluation principles.

What happens if these different shapes (or at least two of them) are applied to a number of different light weight structural projects? The shapes are 1. Bodlund, or rather the equal evaluation principle, ISO 717 when the low frequency spectrum adaptation term $C_{\mathrm{I,50\text{-}2500}}$ is added [11] ($L'_{n,w} + C_{I,50-2500}$) and 2. Hagberg (L_{new}). Topical projects are developed and produced in order to meet the minimum requirement in the Swedish Building regulations, BBR (sound class C according to SS 25267) and nothing more. Then, in terms of requirement levels they must not exceed [6]

- 56 dB using $L'_{n,w} + C_{I,50-2500}$ (= current regulation in Sweden, BBR)
- 61 dB using L_{new}

The results are shown in table 1. In case current requirement is retained it is most likely that these constructions will be more and more common in future. Since the level of the measure is determined by the lowest frequencies the risk for errors increases. Leakage and other high frequency problems which may occur for heavy systems, always might be attended afterwards,

however diffuse low frequency problems often require big efforts afterwards, in case correction measures are necessary.

Table 1: Typical changes of sound classifications for typical light weight constructions which reach are designed to meet minimum requirements, however not if applying the curve shape used to evaluate L_{new}.

	Object 1		Object 2		Object 3		Object 4		Object 5	
Measure	BBR	L_{new}	BBR	L_{new}	BBR	L_{new}	BBR	L_{new}	BBR	L_{new}
Value (dB)	56	64	56	63	56	63	56	65	56	65
Sound class [1]	C	-	C	-	C	-	C	-	C	-

[1] according to Swedish standard SS 25267 (edition 3) [2]

It is obvious that current sound class is no longer valid in case a new evaluation curve is in use [6] instead of traditional ISO evaluation ($C_{I,50-2500}$ included). Nevertheless, further development is needed in order to also include vibration effects and its effect on the experienced low frequency sound / vibrations.

4. ACKNOWLEDGEMENT

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