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Combination rooms for acoustic and energy measurements

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At Danish Technological Institute a dual box-in-box setup is designed for simultaneous measurements of indoor and outdoor heat exchanger systems in relation to energy efficiency and sound emission. This reduces the time needed for preparing and running the combined test, and thus reduce the total cost. A description is given of the combination rooms, the use of short time total interruption of climatic test system while doing the acoustic measurements, and the combination of multiple microphones moved in a controlled manner. Influence of climatic extremes is controlled by calibration measurements at the same conditions according to ISO 3743-1 [1] ‘comparison measurement method using reference sound source’.

1 Introduction

The growing number of energy exchanging units for heating and cooling our buildings and industry have an unwanted side effect called noise, which we have to know, quantify, compare and control.

International regulation demands how to measure and declare the emitted noise at controlled conditions according to established standards.

Until now measurements of energy efficiency and sound have been made in separate rooms in order to control either the ‘climatic’ conditions like stabilized temperature (like minus 22 to plus 25 deg Celsius), humidity and uniform airflow, or the relevant acoustic conditions (low background noise, ‘uniform’ sound distribution and controlled measurements).

At Danish Technological Institute we have designed a dual box-in-box setup for simultaneous measurements of indoor and outdoor heat exchanger systems in relation to energy efficiency and sound emission.

This reduces the time needed for preparing and running the combined test, and thus reduce the total cost.

2 Designs and optimizations towards a combined measurement solution.

2.1 The art of using the given space

The maximal dimensions are limited by the inner surfaces of the existing building, where two neighbouring rooms are used, and a close by room is used for assisting systems.

The original building is made of bricks, concrete pillars and floor, with a shed roof that is not sound proofed. It was significantly improved by finding and closing leaks / covering windows and adding sound absorbents.

The concrete floor could not be ‘cut free’ from the building, and it has a limit for the added weight of the measurement rooms. A large cellar placed under the measurement rooms are mostly used for storage means, and thus disturbances from the cellar are limited.

The two measurement rooms are similar in dimensions. They are mirrored to each other in order to optimize the design with a short sound damped channel used for cooling pipes/duct between the systems in both rooms.

The two cooling 'inner rooms' are rectangular standardized commercial build modular boxes with thermal insulating sandwich walls with thin sheet metal surfaces.

Inner dimensions are 6,5 m * 5,25 m * 3 m giving a volume of 102 m³. According to the measurement standard ISO/EN 3743-1 this allows for measurements of units with characteristic dimensions up to 2 meter. If the volume had been less than 100 m^3 this would be limited to only 1 meter, which would make the rooms more or less useless. Sometimes standards are not so smart….

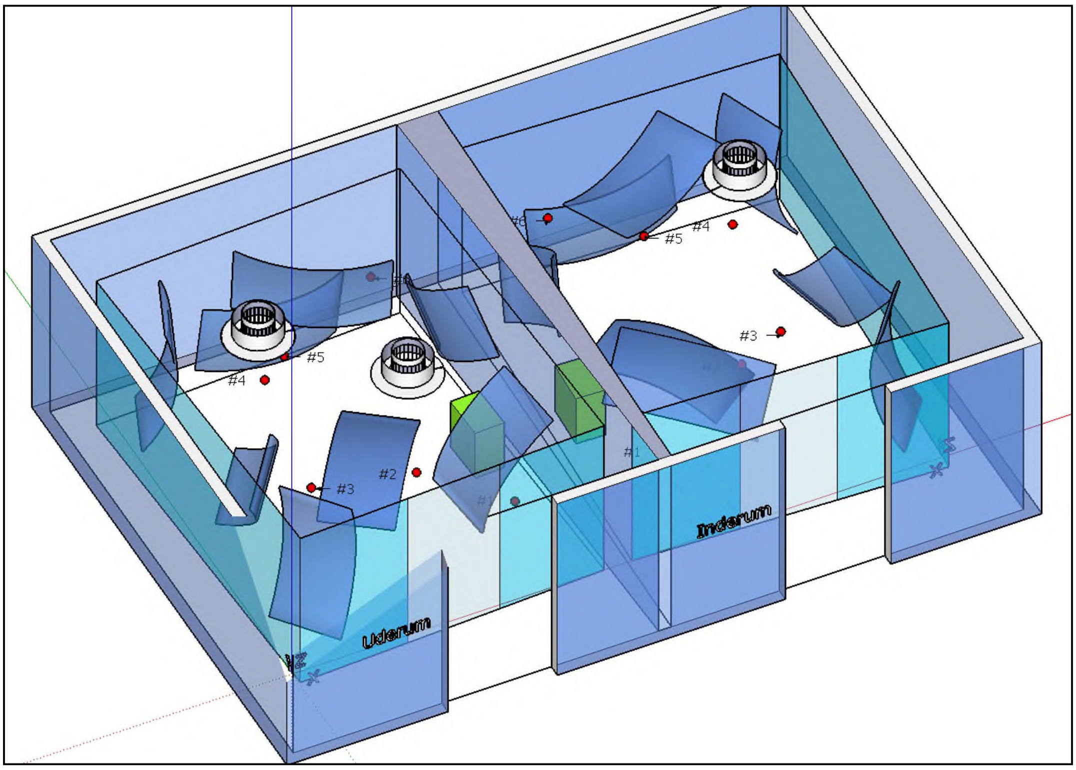

Figure 1 Sketch of the two similar measurement rooms. The double sliding doors are not shown.

The outer sound insulating boxes are made of single and double layer plasterboards. The highest insulation is designed for the walls between the two cooling boxes, where special heavy sound deadened plasterboards are used.

Notice the angulation of the rooms, that will minimize a buildup of resonances due to distances wall to wall.

A noise reduced fan circulate the air between the cooling rooms and the surrounding sound insulating walls to the space above the measurement rooms. This is used in order to minimize possible risk of moisture build up and even icing on the cold outer walls of the coldest cooling box (down to minus 22 deg. Celsius).

A large cooling and heating system is placed in close by neighboring room for establishing the relevant temperature, humidity and airflow around the test units. Especially the coldest room have a double duct system. These high capacity heating and cooling systems are noisy and cannot be sound reduced enough within the given space.

2.2 Shut down and measure the sound.

The trick for measuring the sound from the units is to establish a stabilized situation, where the temperature is within the allowed range but close to the lowest allowed, and then make a quick and total stop of all assisting systems and do the sound measurements as fast as possible before the upper temperature limit are met.

The sound from a heat exchanger unit is normally very steady making it possible to use relative short measurement durations, like series of 2 times 30 seconds. In order to check stability and measurement uncertainty normally 3 to 5 measurements are made.

2.3 Improving the sound diffusity by using reflectors

Acrylic 8 mm thick plates of size 2 meter *1 meter are mounted close to walls and under the roof, using wires and strong magnets clamped to the metallic plates of the cooling rooms.

The mounting wires also bends the plates in order to improve the 'sound spreading' in the rooms.

The use of strong magnets makes it easy to test and move the plates for optimal diffusivity.

The default positions of the reflectors are used for the first test sound measurement. Depending on the evaluation of sound pressure variations during the back and forth movement of the microphones it is sometimes relevant to move some of the reflectors in order to reduce standing waves and their influence on the measurement uncertainty.

2.4 Doing the sound measurements efficiently.

In ISO 3743-1 two methods for achieving a good spatial average of the sound pressure levels in a measurement room are described:

- One microphone moved by a rotating boom on a skewed circular path with a whole number of rotations. This is not chosen due to lack of space for a full rotation of a microphone boom without getting to close to the test unit, the reference sound source, the walls, roof and floor and sound diffusing elements.
- Several microphones mounted on fixed positions, where the number depends on the observed level variations from microphone to another. This is not chosen as the cubic cooling test rooms will give standing wave tendencies, which may result in many microphones and thus an expensive multi number channel system.

Combining these two methods is our solution:

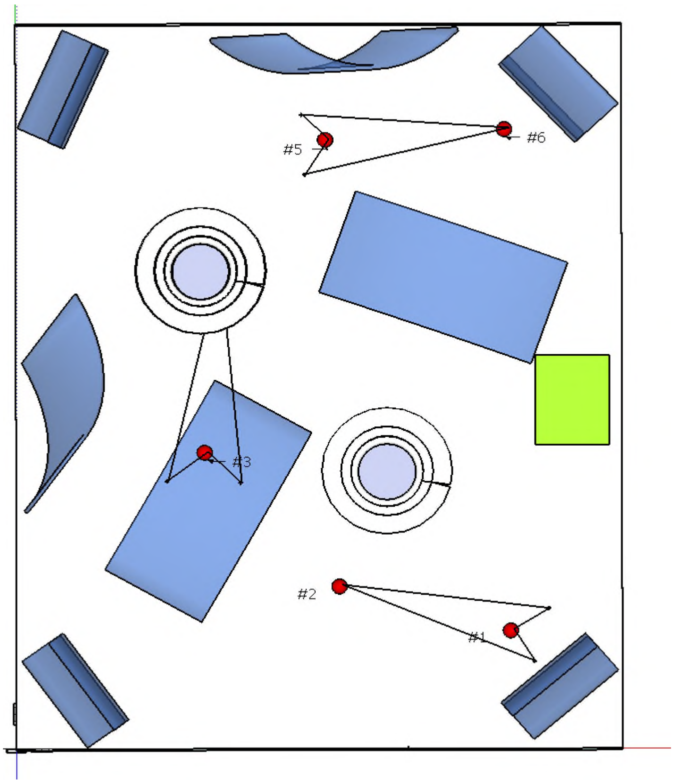

Figure 2 Principle of triple moving microphone system

The average sound pressures of moving microphones on 3 parts of circular paths (arcs) measured simultaneously is used. A radius of 2 meter gives the total microphone path length of more than 5 meter, as demanded by ISO 3743-1.

This combination is not in conflict with ISO 3743-1, but as far as I know not seen used in practice before!

2.5 Using LEGO Mindstorm for testing the triple moving microphone method.

The microphones hang down from the roof in their cables to a lowest position 1 meter above the floor.

By pulling a thin line they are moved along a circular path of 2.1 meter up to a distance of 1 meter from the roof.

Using small ‘boat blocks’, the three lines in each room are lead together out of the rooms through a small hole in the walls. Pulling lines are ‘thin nylon fishing lines’ with low friction and weight.

The original test version was a ”LEGO Mindstorm” setup for pulling the strings with calibrated positions, precise speed and duration, and a parking and reset function. This system was very flexible and stable for testing the methods. Later a less flexible, but probably long time stable step motor system has been designed and implemented.

The motors are placed outside of the rooms in order to reduce the low, but sometimes not low enough noise.

The system is prepared for automatic remote control from the acoustic measurement system.

2.6 Checking the positions of microphones, reference sound sources and test units.

A spreadsheet (Excel) is used for checking the actual positioning of the noise source, reference source and microphone paths in order to fulfil the demands of ISO 3743-1. Here the distances relative to each other as well as to the walls and the plate reflectors are defined. This is also a documentation of the physical setup.

Mikrofon og kilde positioner Varmepumperum

	Placering i meter fra 0,0.						
	x	y	ZA		Dist Mikrofo	Dist Refk	Dist Kilde
1	4,30	1,00	1,00		1,79	2,13	2,24
2	2,80	1,40	1,90		1,82	2,83	3,18
3	1,65	2,60	1,15		1,86	3,00	3,55
4	1,75	4,25	2,00		1,74	3,47	3,92
5	2,70	5,40	1,10		1,77	3,10	3,47
6	4,25	5,50	1,95		4,60	3,01	3,06
RefK	4,50	3,00	0,30				
K1	5,10	3,00	0,40			0,61	

Frekvens 100 giver Lambda/2 = 1,70 = mindste afstand mellem mikrofonerne.

Overskridelse vises med røde tal under 'Dist Mikrofoner'.

Mikrofonpositioner set fra oven med nummer og højde H **Set fra side ind mod kilde:**

Reflektorskærme omtrentlig placering...

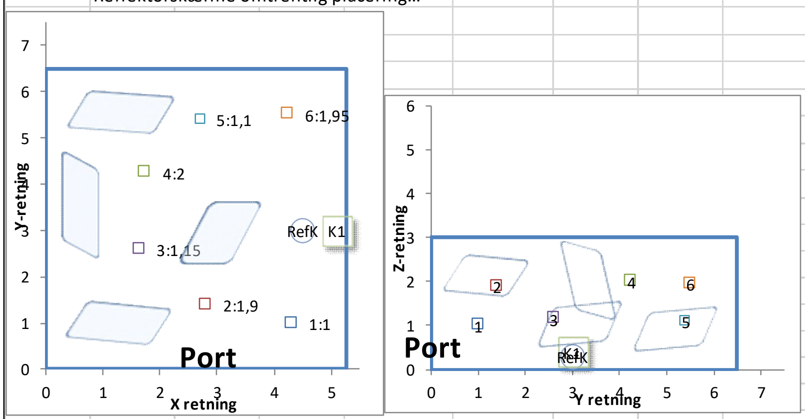

Figure 3 Spreadsheet for checking positions and distances according to ISO 3743. (Danish text)

2.7 Easy to use measurement system hardware and principles.

- NorSonic-850 hardware 7-channel. LAN-controlled by PC based software implementing the ISO3743-1 for a double room setup (2 time 3 microphones) and an extra microphone used for background noise measurement.
- 7 GRAS 40AE_26CA microphones + preamps + long cables.
- 2 Nor-278 reference sound sources.
- 1 Brüel & Kjær type 4231 sound pressure calibrator.

All components are regularly externally calibrated according to demands from the certification authority (DANAK)

Internal control and comparisons of microphones and reference sound sources are made regularly.

The ‘tough’ climatic conditions (temperature and humidity) makes extra control and handling needed, but until now no problems have been observed.

2.8 Control, document and correct for background noises

When measuring in one room there may be disturbance from the other room and from external noise sources.

However as sound measurements are made simultaneously in both rooms, it is possible to calculate if noise in one room may disturb measurements in the other room by knowing the sound insulation between the rooms.

A microphone placed above one of the room in the space between the room and the shed roof of the building makes it possible to evaluate if external noise protruding the roof may disturb any of the rooms. The sound insulation from this microphone to both measurement rooms are measured. The same microphone signal is shown on the measurement system display for visual check on line while measuring.

These sound insulation values are measured when the reference sound sources are used one at a time during the normal measurement sequence for establishing the ‘reference sound power value’ relevant for the comparison method.

The sound insulation between the rooms may be influenced by the actual ‘quality’ of the connection duct. So if dual sound measurements are to be made a check of possible leaks here are tested also.

All microphone signals may be directed to a headphone and loudspeaker for subjective listening of background noises, as well as checking for not expected sounds and variations from the tested units.

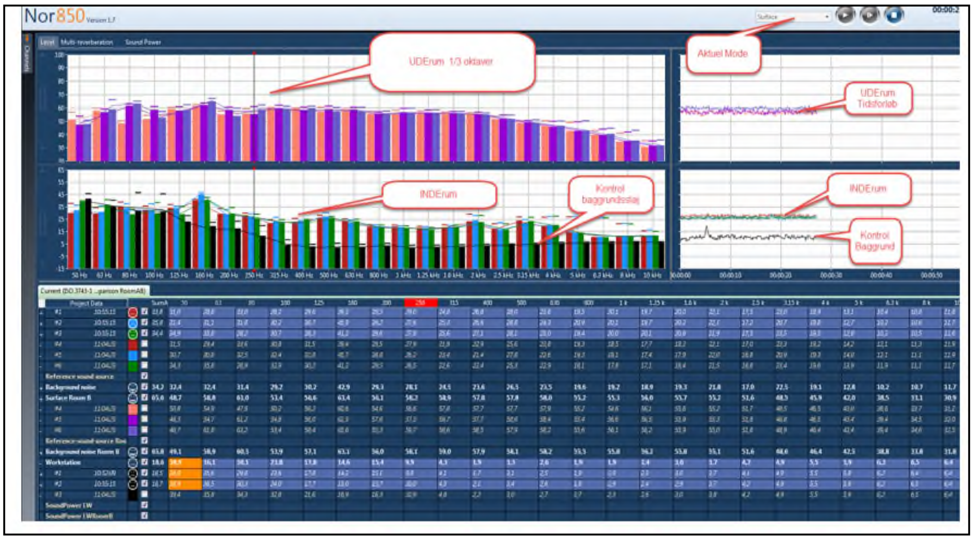

Figure 4 Display setup showing 1/3-octaves, averages, time story and data tables. (Danish text boxes)

2.9 Smart use of spreadsheet for analyses and documentation.

All the 1/3-octave analysis results of the microphone signals are saved and controlled in a dedicated spreadsheet template, where possible disturbances and variations inclusive estimates of measurement uncertainty are calculated immediately.

This same spreadsheet calculates the 1/1-octave values and the total 'A-weighted uncertainty' based on the actual frequency spectra.

The results are then documented in final report sheets with data tables, curves, instrument ID's, and Digital Signature.

3 Summary

At Danish Technological Institute a dual box-in-box setup is designed for simultaneous measurements of indoor and outdoor heat exchanger systems in relation to energy efficiency and sound emission. This reduces the time needed for preparing and running the combined test, and thus reduce the total cost. The acoustic measurements implement combination of methods, hardware setup and dedicated spreadsheets for checking data and producing final reports.

4 References

[1] ISO 3743-1 " Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for small movable sources in reverberant fields. Part 2: Comparison method for a hard-walled test room "
This implies a simple 'on line' correction for temperature and humidity influence.

[2] DS/EN 12102: 2013. " Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors for space heating and cooling – Measurement of airborne noise – Determination of the sound power level ".
This is defining normal setups and preferred acoustic measurement standards.

[3] ISO/EN 9614-2 " Acoustics – Determination of sound power levels of noise sources using sound intensity. Part 2: Measurement by scanning "
This could in principle be used, but the duration for measuring on several measurement surfaces would be a problem. Especially when temperature is low like minus 22 deg Celsius.