FAN NOISE CONTROL – CASE OF DATA CENTERS

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SUMMARY

Data center inner and outer noise is mostly generated by fans. A simplified modeling of data center noise radiation demonstrates that the major limiting factor to noise reduction is the low frequency produced by medium to large fans operating at low speeds (mostly air conditioner units in server rooms and dry coolers on rooftop of building). A wide range of typical passive means of noise reduction and some tricky situations are mentioned.

As a digest of its experience, CETIM put forward a step-by-step state of noise issues in data center industry, and presents its "sustainable noise management" approach of data center design.

INTRODUCTION

In order to meet demand of ever-growing internet flows, particularly with the upcoming cloud technology, data center industry is growing rapidly: from 2005 to 2010, total electricity used by these installations increased by +56%, reaching 1,3% of all electricity used in 2010 in the world [1].

While energy efficiency is one of the most critical design parameter for data center companies and is also a care for some internet users, noise of web industry remains quite unknown.

Indeed, such gatherings of computers absolutely form industrial facilities. They can host up to several dozens of megawatts, mainly for the needs of ventilation (servers, air cooling and handling systems). These equipments generate noise levels that are comparable to those of mechanical industry.

Given the demanding regulatory framework (2002/49 and 2003/10 European Directives respectively for environmental and occupational noise, plus country-specific regulations), data center industry copes with the issue of integrating noisy equipments in urban and rural soundscapes.

After showing how data center noise issue comes down to fan noise, this paper draws up a list of noise reduction solutions to be examined. Then, a method built up for controlling noise during the whole data center design and development process is presented and confronted to the tight requirements of this emerging industry.

DATA CENTER NOISE SOURCES

Definition of "data center"

According to wikipedia.org, a data center is *"a facility used to house computer systems and associated components, such as telecommunications and storage systems. It generally includes redundant or backup power supplies, redundant data communications connections, environmental controls (e.g., air conditioning, fire suppression) and security devices."*

Though being brief, this definition lists all the categories of noise sources that will be discussed.

Operation of a data center – main noise sources

Servers are placed in 2 meters high racks, with their hot air output always on the same side of the rack. These racks are usually arranged in rows, forming alternately hot and cold aisles. CRAC (Computer Room Air Conditioning) units are in charge of cooling hot air pulled from the top of the room. This cooled air is pushed in the raised access floor, and reaches the cold aisles of server racks via perforated tiles. Cold aisles can be covered, insuring that the whole cold air flow supplies every server.

CRAC are made of fans pulling hot air through exchangers that are fed by a cold water network. The refrigeration of this network is produced by auxiliary equipment, often located away from client rooms (on rooftops and/or in technical rooms). It consists in the association of 2 machines that are sometimes combined in a single one: chillers (pumps and compressors) and dry coolers (heat exchangers and fans, using outdoor air).

Description of noise sources

The following table shows a synthetic view of the noise sources encountered in a data center. They are sorted in categories, showing that most part of noise comes from fans.

Table 1: Description of data center noise sources

Category	**Noise sources**	**Noisy subsystems**	**Operation % of day**	**typical location**
Racks	Servers, routers, storage...	***Fans (medium/high frequencies)***	100	Server rooms
Cooling system	air conditionner units (CRAC)	***Fans (low frequency)***	100	Server rooms
	chillers	Pumps, Compressors (medium frequency)	100	Technical rooms If soundproofed : Rooftops
	dry coolers (condenser)	***Fans (low frequency)***	100	Rooftops
Security	Air Handling Units	***Fans (low frequency)***	100	Rooftops or technical rooms
	Smoke Ejection System	***Fans (low frequency)***	1	
Power supply	Transformers	Electromagnetic noise	100	Technical rooms
	UPS (Rectifiers)	***Fans (medium frequency) Electromagnetic noise***	100	
	Batteries		100	
	Diesel (electricity generator)	Engine + dry coolers on rooftop	1	

Note: Noise sources of occasional use such as electricity generators (engines and associated condensers), smoke ejection fans (features huge air flow) are out of scope of this study, as their operation is not typical of the operation of a Data Center. Indeed, they are used less than 1% of time.

Noise regulations concerning data center industry

<u>Occupational noise:</u>

In Europe, occupational noise is regulated by the 2003/10/EC directive. It specifies an exposure limit value of Lex,8h = 87 dB(A) (taking into account possible ear plugs attenuation) which can be quite easily met. Besides, two exposure action values (lower: Lex,8h = 80 dB(A); upper: Lex,8h: 85 dB(A)) are specified, regardless of any hearing protection. Though these two values may be exceeded as long as the exposure limit value is not crossed, a scope of action has to be undertaken in accordance with the directive. This notably includes exposure assessment and setting up a noise reduction policy.

<u>Environmental noise:</u>

European countries generally impose noise level limit values at property line of industrial facilities. A few countries, as France, also use an « emergence criterion » which assesses noise impact of the installation over existing noise (without this installation).

Besides, 2002/49 European directive also weighs in environmental noise concern. Though specifying no noise limits, it leads local authority to assess environmental noise levels and to identify noisy areas to be improved, with the help of noise maps.

CASE STUDY – SIMPLIFIED MODELING OF DATA CENTER NOISE

Introduction

Let us consider a data center defined as following: the building is 30 m long by 30 m wide, consisting of 3 floors plus a technical rooftop hosting chillers and dry coolers. Total building height is 15 m. Sound pressure level is assessed at a receiver point located on ground at 30 m in front of one of the facades, at property line.

Note: This simplified modeling is only a demonstrator. Absolute noise levels shall not be interpreted ; only balance between low, medium and high frequencies and order of magnitude of acoustic treatments performance matter for the needs of this demonstration.

2 cases are studied and compared:

- case study #1: standard design, without any specific noise reduction device : glass facade and standard rooftop installation (simple surrounding barrier). Rooms have no acoustic absorbent material

- case study #2: improved acoustic design (though not pushed to its end) : a concrete facade (featuring much better insulating properties than glass) and a heavily soundproofed rooftop installation ; even though it is an efficient solution, for the needs of representativeness, rooms remain deliberately free from sound absorption treatment, as it is often neglected in data centers

Case study #1 – With glass facade, and standard rooftop installation

Both following tables 2 and 3 show, step by step, for each of the case studies, a simplified reasoning for modeling the noise of a data center. It assumes that only one facade, and the whole rooftop equipment radiate to the receiver point.

Sound pressure levels, sound power level, attenuation values are derived from field measurements in data centers. They are given in the form of simplified spectra, allowing clearer demonstration. Spectrum range from 63 to 16000 Hz has been divided in 3 ranges of 3 octave bands each:

- 63 to 250 Hz unweighted bands are summed as Low Frequency (LF) level

- 500 to 2000 Hz unweighted as Medium Frequency (MF) level

- 4000 to 16000 Hz unweighted as High Frequency (HF) level

Overall sound pressure and power levels are A-weighted.

Each table is built up as following:

- Room SPL: according to typical noise levels measured in data center rooms, server and CRAC noise are assessed and summed, with the addition of room amplification

- Facade noise: Only one of the four building facades is considered (the one facing the receiver). Room reverberated total SPL is attenuated by the facade wall, which sound insulation properties (given in the form of attenuation values) vary highly with frequency. The output SPL is then multiplied by the radiating area, which gives an assessment of its sound power level

- Rooftop noise: cooling and air handling systems are considered as a whole, in terms of a overall sound power level. Sound attenuation of either sound barrier or enclosure (according the case) in taken in account

- Finally, facade and rooftop sound pressure levels at receiver point are individually derived from their respective sound power levels, with relatively slow sound propagation: due to an urban-type reverberant environment, it is supposed to be less around 4 dB for each distance doubling. Final total SPL at receiver point is obtained by summing both SPL contributions of façade and rooftop.

Table 2: Simplified modeling - Case study #1: standard design

	frequency range (Hz) →	63, 125, 250	500, 1k, 2k	4k, 8k, 16k	global dB(A) Level
		LF (dB)	MF (dB)	HF (dB)	
Room SPL	servers	55	70	65	71
	CRAC	**82**	70	55	72
	servers + CRAC	82	73	65	74
	room amplification	**10**	8	6	-
	total room SPL	92	81	71	83
Facade Noise	attenuation of a glass wall	**10**	25	40	-
	resulting wall surface SPL	82	56	31	67
	size (m2)	450	450	450	-
	total facade SWL	103	77	52	88
Rooftop Noise	chillers/dry-coolers/AHU PWL	**110**	100	85	101
	barrier effect	**5**	15	20	-
derived SPL at property line	facade SPL @30m	**75**	49	24	60
	rooftop SPL @30m	**72**	52	32	59
	TOTAL SPL @30m	**77**	54	33	62

Final SPL value shows that:

– low frequencies (63 to 250 Hz) tend to be the major part of this data center noise: indeed, 500 Hz to 16 kHz noise is 8 dB less than total SPL

– despite moderate SPL surface levels, once multiplied by huge radiating area, facade noise is not to be neglected (same weight in total SPL than rooftop noise)

Case study #2 – with concrete facade and heavily soundproofed rooftop installation

In this case, glass wall, which is identified as a poor sound barrier for room noise, is replaced in the modeling project by a concrete wall, and heaving soundproofing (full enclosure design) is added to the acoustic barrier on rooftop.

Table 3: Simplified modeling - Case study #2: improved acoustic design

	frequency range (Hz) →	63, 125, 250 LF (dB)	500, 1k, 2k MF (dB)	4k, 8k, 16k HF (dB)	global dB(A) Level
Room SPL	servers	55	70	65	71
	CRAC	**82**	70	55	72
	servers + CRAC	82	73	65	74
	room amplification	**10**	8	6	-
	total room SPL	92	81	71	83
Facade Noise	attenuation of a concrete wall	**25**	50	70	-
	resulting wall surface SPL	67	31	1	52
	size (m2)	450	450	450	-
	total facade SWL	88	52	22	73
Rooftop Noise	chillers/dry-coolers/AHU PWL	**110**	100	85	101
	barrier effect	**25**	50	40	-
derived SPL at property line	facade SPL @30m	**60**	24	-6	45
	rooftop SPL @30m	**52**	17	12	37
	TOTAL SPL @30m	**61**	25	12	46

The effect on total SPL of this improved acoustic design over standard design (case study #1) is significant: total noise reduction reaches 16 dB(A) at receiver point.

Despite the concrete facade, room noise still radiates through it, and remains the main noise source (45 dB(A), versus 37 dB(A) for rooftop noise).

Further noise reduction of facade noise would mean reducing LF noise. Indeed, MF et HF noise (respectively 24 dB(A) and -6 dB(A)) contribution is null on overall level. Note that at this stage, in addition to possible reinforcement of LF performance of facade, each dB of reduction achieved in room noise by means of better choice of machines, acoustic absorption treatment, etc. (see next section for more information), would have an immediate impact on global SPL noise at property line.

TYPICAL NOISE REDUCTION IN DATA CENTER

This section presents a non-restrictive scope of standard passive means that can be used to reduce noise in data centers. Both careful choice and combining of solutions can significantly reduce noise levels, especially at low frequencies.

Room noise

Why reducing room noise ? To comply with occupational noise regulations, and it helps controlling environmental noise pollution because facade noise directly depends on ambient room sound pressure levels.

- Machines:
  - servers and other customer equipments: choice of units, racks (sound proofed racks exists), influence of cooling type (ambiant air cooling, hot/cold aisles, liquid cooling)
  - CRAC: choice of more silent units, homogeneous balance of air flow on units (including redundant ones), operating oversized machines at lower fan speeds than nominal conditions
- Spatial sound distribution and propagation: rack density, sound absorbent dividing walls, sound absorbent ceilings and walls.

Facade noise

Why reducing façade noise ? To comply with environmental noise regulations. Indeed, even if noise levels radiated by walls are usually very low, they are "acoustically multiplied" by large areas, which leads to PWL that are comparable to those of rooftop equipments. Moreover, due to its height, this type of noise source will not be shielded by any acoustic barrier at property line.

- Choice of insulating properties : material, thickness, possible doubling of existing walls
- Careful vibratory isolation on every machine, including server racks, in order to avoid:
  - In case of very low noise level limits : vibration transmission through floors and walls to building facades or roof, that can radiate noise in environment
  - Vibration transmission to possible attached residential buildings
  - Loss of performance on data storage units, meaning loss of energy [2]
- possible sound insulating weaknesses of facades, which would need acoustic doubling, acoustic silencers or relocation at "safer" places:
  - smoke ejection and air handling intake / exhaust (dampers, grilles)
  - glass window: compared to a wall, it can be considered as an "open window" for noise
  - doors: simple doors, or doors without any joints, or with ineffective ones

Rooftop noise

Why reducing rooftop noise ? To comply with environmental noise regulations. This is the most obvious noise source to be treated; as said for façade noise, it is mandatory to reduce rooftop noise at its sources. Indeed, possible acoustic barriers at property line will not have any significant shielding effect on noise sources located at such height.

Strong space and height restrictions for rooftop cooling devices lead to compact machines, with high output air velocities, large fans very close to each other, extremely low available pressure.

Of course, low noise versions of cooling systems are offered by manufacturers. As for CRAC units, their offer oversized machines operating at lower fan speeds than nominal conditions. Such design features extreme low frequency content and small amount of available pressure drop.

Still, it happens that even the quietest version of the range is unacceptable; when noise reduction on these already "silent" versions is needed:

- around 10 dB(A) reduction: with an adequate combing of following solutions, satisfactory results can be obtained, without any significant loss of energy efficiency:

- tunnel-type silencer (with no baffles, insuring a negligible pressure loss) for air output
- noise barriers + refraction edges
- absorbent carpeting of possible rooftop surrounding walls

CAUTION: due to typical screening effect issues, these types of solutions will efficiently shield residents if they are located at a similar or lower level than the machines.

- around 20 dB(A) reduction: in this situation, only splitter silencer can achieve such performance; but silencer design often comes to the following vicious circle:

  {need of pressure drop} => {modification of the machine} => {raise of machine noise level}

  which means less noise reduction than expected. The second side effect is that the raise of machine noise occurs mostly at low frequencies, which means even larger silencers. Consequently, getting out of this dead-end requires a lot of space for massive enclosures (that can double or triple the space required by machines themselves). It generally implies that the issue has been identified a stage of pilot studies, prior to installation. Weight can be also be an obstacle, especially on rooftop.

Best performance are obtained with a concrete building with large arrays of silencers at bottom and top is by far the best solution, but it is nearly impossible in case of existing installation, assuming that it has been taken into account at the stage of building design.

Thus, a noticeably wide range of passive means of noise reduction is offered for data center design.

FAN NOISE CONTROL IN DATA CENTERS

After describing this sector's strong issues, this section will show that a specific noise-control method (during data center design and development process) is essential to ensure that noise level targets will be reached.

Data center noise reduction encounters specific issues and restrictions which can be summarized as following:

- lack of room (needs anticipation of required space for noise reduction), optimization of profitable area
- continuity service:
  - needs to be "right the first time"
  - 24/24 operation implies high risks of noise annoyance (night periods, public holidays)
  - the latest Tier IV standard insuring the highest availability rate means strong redundancy and oversized power and cooling capacities
- energy efficiency requirements (energy consumption is a major part of data center budgets, and current European regulatory burden on Energy Using/Related Products – EUPs/ERPs) :
  - raising temperatures in rooms, as recommended by ASHRAE
  - free cooling technology, which requires noisy massive air outputs
- demanding clients: lack of flexibility in room design, commercial interests versus acoustical requirements

– dynamism of market, fast answer to clients needs, implying that everything is planned in advance

Such a range of requirements shows the necessity to build up specific working methods, to be able to integrate a noise reduction policy in the process. The method developed and used by CETIM closely follows examples used in design process of other similar industries, and then have been gradually adapted, experience after experience.

This "sustainable noise management approach" it is synthesized in the following table 4.

The first main line of this table is about regulations, noise limits, development strategy and plans, which comes within the competence of the data center owner and its acoustic expert.

The following two lines deal with project detailed design (noise reduction solution sizing) and construction, which is often subcontracted to design offices and their assisting acoustic design offices. During these steps, close monitoring and approvals by contracting owner are required.

Table 4: "Sustainable Noise Management Approach" for data centers – Source : CETIM 2011

Action scope	Development process	input data	output data
Company's site management	Risk assessment	Local planning authority documents	Identification of risk zones Guidelines for general implantation of building and/or equipements
		Regulations	
		Location of residential areas	
		Company's QHSE management policy	
		Former acoustic measurements	
	Noise impact study of the complete site	Company's long term (full capacity) development plan	Complete site noise impact study
	Assignment of project-specific noise targets	Company's development planning	Project-specific noise targets, for each identified step of development
Transferring general requirements into project requirements	Project launch	Project-specific noise targets (see previous lines) Pilot study with first technical data (machine sizing, numbering and lay out)	Requirements document: For each technical items including individual noise limits (machines, building) derived from project noise targets
Project management	Project execution and monitoring	Complete technical studies (building, powering and cooling systems)	Validation of design calculation note: description, sizing, efficiency of acoustic treatment
	Project technical acceptance and commissioning	Acceptance measurements	Validation of acceptance document

The most challenging part of this method is to be able to achieve its integration in decision processes and development plans of data center companies, ensure its successful transferring to subcontractors, until satisfactory acceptance measurements.

CONCLUSION – FUTURE OUTLOOK

Conclusion

Data centers, as any industrial facilities, are liable to face noise issues concerning their integration in urban areas. Noise reduction can be achieved with smart choice and combining of solutions among a large scope of existing means. Nevertheless, data center acoustic design shall particularly focus on low frequency sources interacting with building performance.

Moreover, these apparently easy-to-make technical choices often counter major stakes of data center design (profitable of space, energy efficiency, short design study periods). Moreover, installation modification is almost impossible as soon as they are under operation.

This is the point where an adequate working method becomes essential. The “sustainable noise management approach” put forward by CETIM answers to this situation; indeed, only an association of an experienced acoustic expert, a risk assessment approach, acoustic modeling, robust acoustic requirements documents and close monitoring can ensure reaching such quality approach requirements.

Future outlook

In case of strong noise reduction requirements, implying the use of splitter silencers, the choice of machine with oversized fans operating at low speeds may not be always the best solution as it generates extremely low frequencies, for which passive noise reduction has obvious limited performance.

In order to identify possible solution to this vicious circle, an extensive parametric analysis study can be considered, using relationship functions between sound power level spectra and fan design parameters (air flow, pressure drop, size, etc.), including standard noise reduction means performance models, may identify sets of choice that would optimize overall noise levels, energy efficiency and size of the complete device (including noise reduction devices).

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