inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 3.7

COMBUSTION TURBINE EXHAUST SYSTEMS- LOW FREQUENCY NOISE REDUCTION

G. Kudernatsch

ABB TURBO SYSTEMS LDT., Thermal Machinery Laboratory, CH- 5401, Baden, Switzerland

Tel.: ++41 56 205 44 33 / Email: guenter.kudernatsch@ch.abb.com

Keywords:
GAS TURBINE, EXHAUST SYSTEM

ABSTRACT
Gas turbines facilities are steadily moving closer to populated areas. To avoid neighbourhood noise complaints, low frequency noise level limits were added to the generally used dB(A) limit. The primary source of the low frequency noise emission of the plant is the exhaust system. To achieve the necessary attenuation, large dissipative silencer systems with baffle thicknesses up to 800 mm have to be installed. Such systems are extremely costly and cause additional pressure drop. To remedy such disadvantages, an investigation and optimisation into the noise sources was performed. One of the main results of the investigation was that the low frequency portion of the exhaust noise is influenced considerably by the turbulent flow field in the exhaust system. Obviously then, any known source mechanisms governed by turbulence phenomena should be minimised.

1 - INTRODUCTION
There was a trend during the last years that power generation facilities based on combustion turbine are located in increasingly populated or residential areas. In order to avoid disturbances, in addition to the generally used A-weighted sound pressure level limits, low frequency noise are commonly included in many acoustical specifications. Since the primary source of the low frequency noise emission of the power plant is the gas turbine exhaust system with low frequency power level in the range of $125 - 140$ dB radiated from the stack outlet, such noise emission then have to be reduced considerably. As a realistic goal, depending on the distance to the next neighbourhood and the number of units installed, a power level of $110 - 115$ dB radiated in the 32 Hz octave band should not be exceeded. To achieve such attenuations, usually large dissipative silencer systems with baffle thickness up the 800 mm have to be installed. Because of their huge dimensions, exhaust systems designed in such a way are expensive and not economic because of the resulting pressure drop. To avoid such disadvantages of add-on attenuating devices, an investigation and optimisation was performed, considering all relevant acoustical aspects of such systems. One of the main results of the investigation was, that the low frequency portion of the exhaust noise will depend on the system design itself.

2 - IDENTIFICATION OF NOISE SOURCES
The noise spectrum at the turbine exhaust is very complex and is caused by multiple noise sources. Mid and high frequency components are related to aerodynamical sources such as turbulent jets exhausting into the system, flow interaction with internal supports or surfaces and combustion roar. High frequency tones are generated by the rotor stator interaction and low frequency tonal noise can be related to combustion instabilities. The sum of all the different noise sources radiates via the diffuser into the exhaust duct and represents the noise input into the exhaust system. It will be used as basic input for the calculation of the necessary means to fulfil the acoustical requirement. Based on the nature of these different sources, the total noise exhausted into the stack should not be dominated by low frequencies. Nevertheless, in most of the cases the typical power spectrum presented for the turbine outlet shows large low frequency elements, mainly in the 32 Hz octave band, which are essentially associated to unstable combustion or rumble characteristics of jet noise. However, even in absence of combustion pulsation intensive low frequency levels characterise the exhaust system. Therefore, in order to design effective

and economical measures to reduce the most disturbing low frequency content, the nature of the source must be understood. To identify the reason, costly acoustical investigations on a 40 MW gas turbine test rig were performed.
The test rig was equipped with a standard exhaust system with a silencer installed in the vertical part of the 16.5 m high stack (see Fig. 1). To investigate the silencer performance with hot gas conditions the turbine was also operated without silencer.
During all the tests, the combustion pressure fluctuations inside the combuster were monitored with pressure sensors.
As an important feature, the behaviour of the combuster could be varied continuously during the tests. It enables to investigate the influence of combuster related noise to the stack noise.

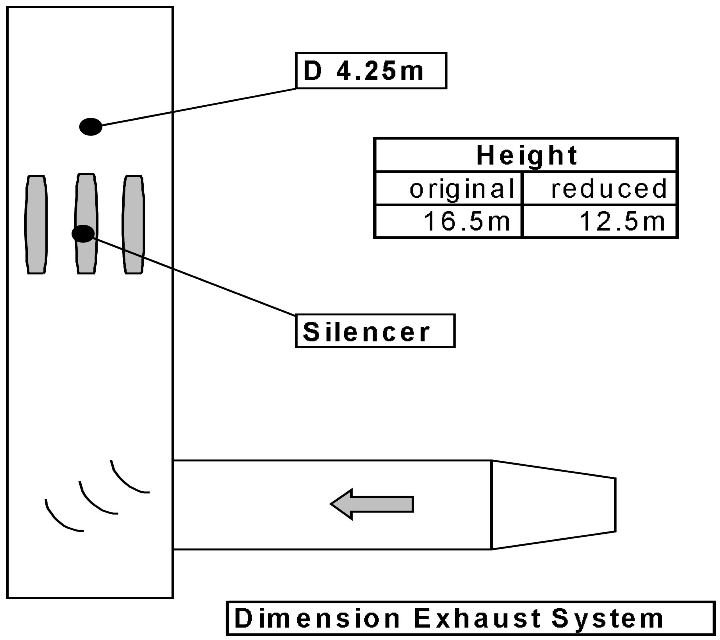

Figure 1.

Octave band measurement at the stack outlet show the typical increase of the low frequency levels in function of the load.
Between idling and base load the sound power level in the low frequency range at the stack exit rises by approx. 10 dB.
To get more detailed information apart from octave and 1/3 octave band measurement, also narrow band analysis with constant frequency band width were performed.
Even if the combustion transducers indicate absolutely stable combustion without any tonal components, the noise character at the stack outlet is definitely not random as it could be expected if the increase in the low frequency region would be generated by turbulent flow. The noise consists of multiple tonal components which are changing frequency and amplitude in function of the temperature, corresponding to the speed of sound.
It is obvious that such an acoustical behaviour could not be generated by unstable combustion. Pulsating combustion is usually characterised as a single tone (including harmonics) with constant frequency. Such a behaviour, a frequency shift in function of the speed of sound is typical for cavity resonances
To prove this theory

- the acoustical eigenfrequencies (organ pipe modes) of the exhaust system were calculated using a finite element method and
- the findings were checked experimentally by additional measurement with a reduced stack height (4 m)

Results:

- Even if all the analytical formulations describing the inlet side (rotating turbine blades) and outlet of the system (stack exit) used for the calculations are approximations, the resulting frequencies, at least in the range up to 50 Hz, correspond to the measured ones.

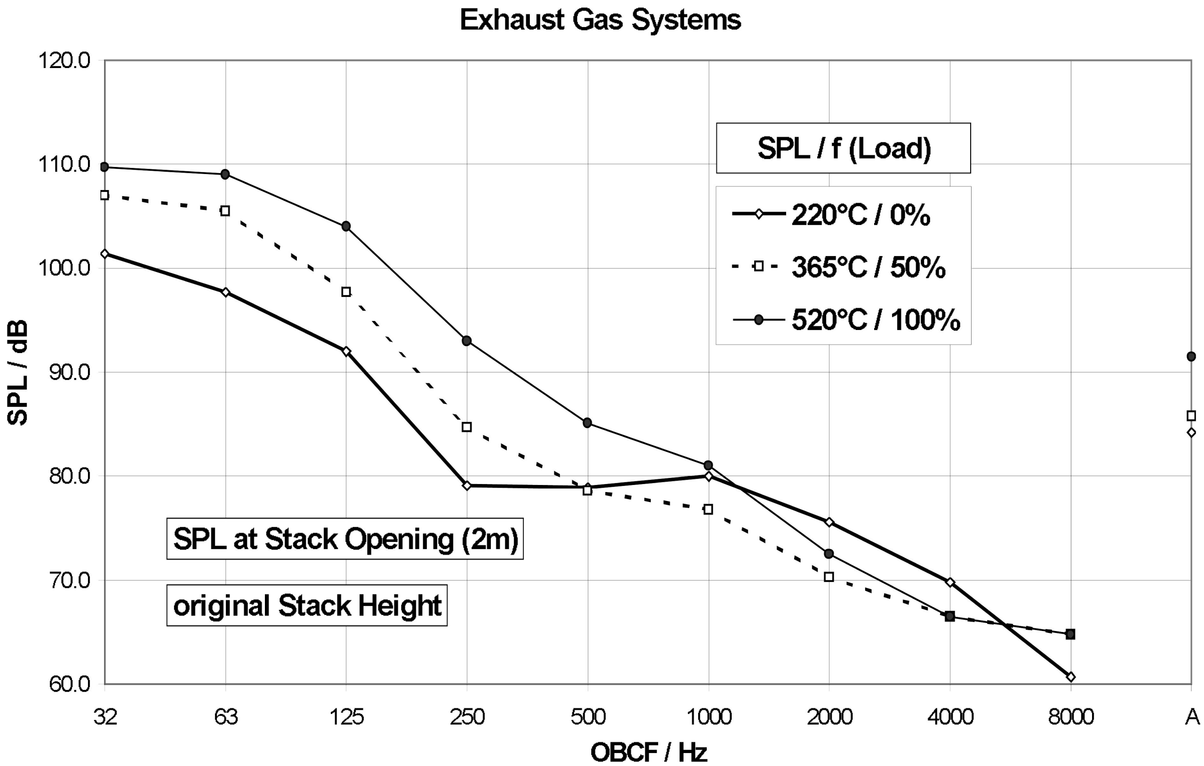

Figure 2.

- The result of the measurement for idling and base load, a frequency shift according to the difference in stack length, is shown in the diagrams Figs. 4 / 5.

These results demonstrate that the low frequency contribution radiated from the stack exit, at least in the absence of tonal combustion pulsations, is caused by standing wave effects. The strong coupling between an acoustical source, which is at the moment not known and the connected duct system generates these peaks in the low frequency region. This implies for instance, that changes in the duct dimensions and the boundary conditions will significantly influence the acoustical response and therefore, the low frequency levels downstream of a given turbine. As a consequence, the low frequency sound power level which is used to determine the necessary acoustical means for a combined cycle plant will be different for combined cycle and open (bypass) cycle operation.
In a next step the nature of the acoustical source or sources which is responsible for the low frequency noise has to be detected.
There might be two possibilities:

- noise caused by combustion instabilities
- aerodynamical sources

Even under normal operation conditions the combustion is not completely stable. "Moderate" pulsations will lead to pressure fluctuation at the outlet of the gas turbine. These pulsations could represent an acoustical source. Usually, these pulsations are single tone components and it is clear if such frequencies coincide with the standing wave pattern, a resonant amplification of the level can result. Correspondingly, increases of the low frequency noise emission of the stack will occur. However, to cause a low frequency pattern as measured at the stack exit, a random excitation would be necessary.
Sources which would fulfil these conditions could be for instance separations in the turbulent flow field of the system. Although the power driven by the turbulent flow field is low, the acoustical answer from the system can be considerable, because the plane waves propagating in the system will be totally reflected at the exit. This means, any known mechanisms in the system leading to turbulent phenomena should be avoided or at least minimised.

3 - SOLUTION CONCEPT

In order to determine the main sources of acoustic power within the turbulent flow field in the exhaust system, a CFD tool based on Lighthill's acoustical analogy has been built up. This tool can be used as

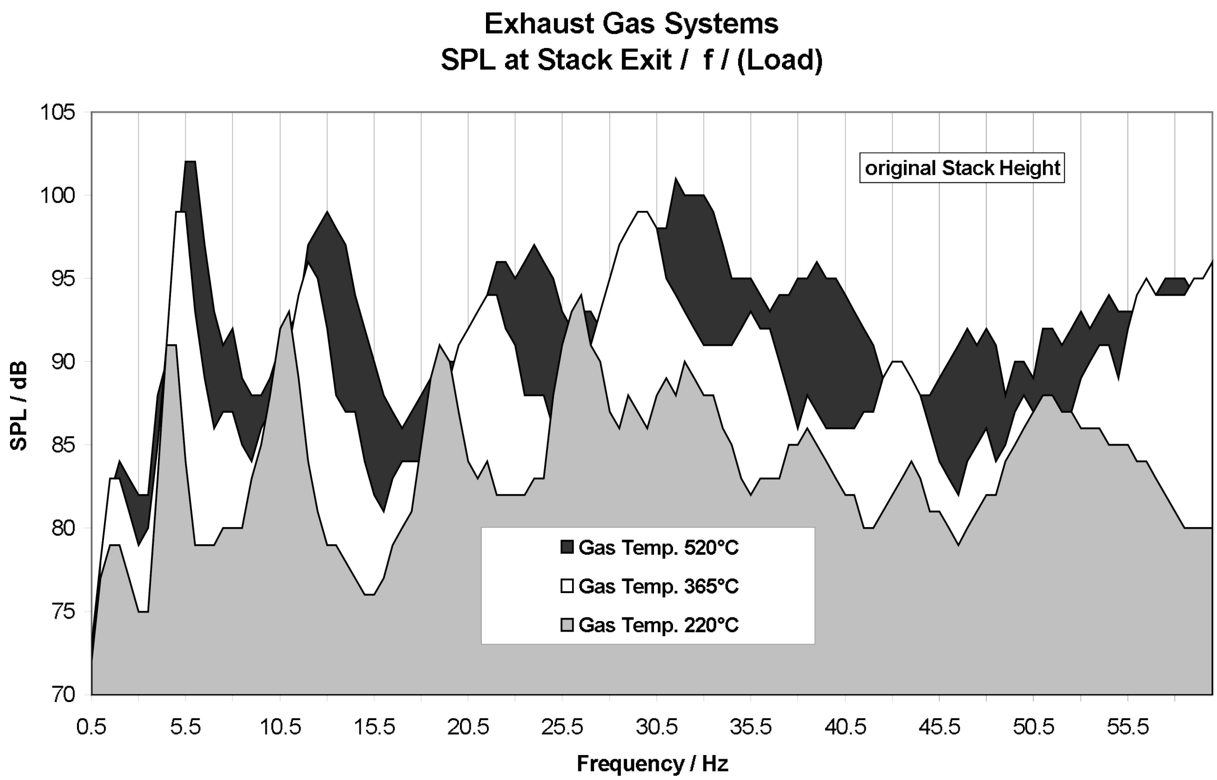

Figure 3.

a postprocessor on a steady state CFD- computation with homogeneous turbulence modelling. Three different source mechanisms, based on Reynolds average quantities, have been considered: Jet noise, convective transport of vorticity and the impact of large scale secondary flow structures.

In the fluid analysis, the exhaust system with all structures such as silencer and vanes, is represented by a considerable number of three dimensional cells. For each cell, all the different aerodynamical parameters necessary to determine the acoustical behaviour, e.g. velocity components, pressure, density or turbulent kinetic energy are computed.

The computed results are used to optimise the design of the system aerodynamically with consideration of the acoustical aspects. For instance, flow separations which are caused by abrupt area changes (thick silencer baffles) or bends without guide vanes will be minimised.

The reduced low frequency emission of such a design has been demonstrated in Fig. 6. Compared to conventional designed exhaust systems (see Fig. 7), the measurements on exhaust systems with the new "slim" design confirm the considerably improved low frequency emission of the stack exit. An additional benefit of such design is a reduced pressure drop which influences positively the overall performance.

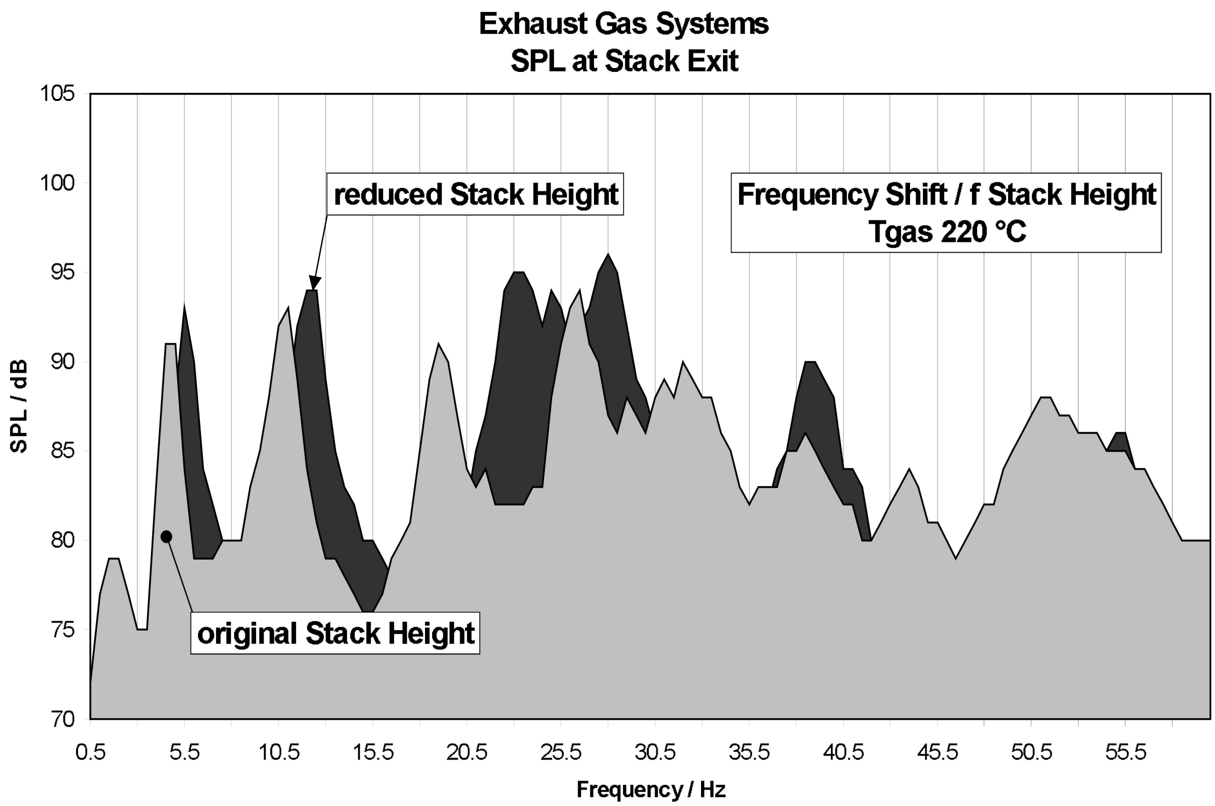

Figure 4.

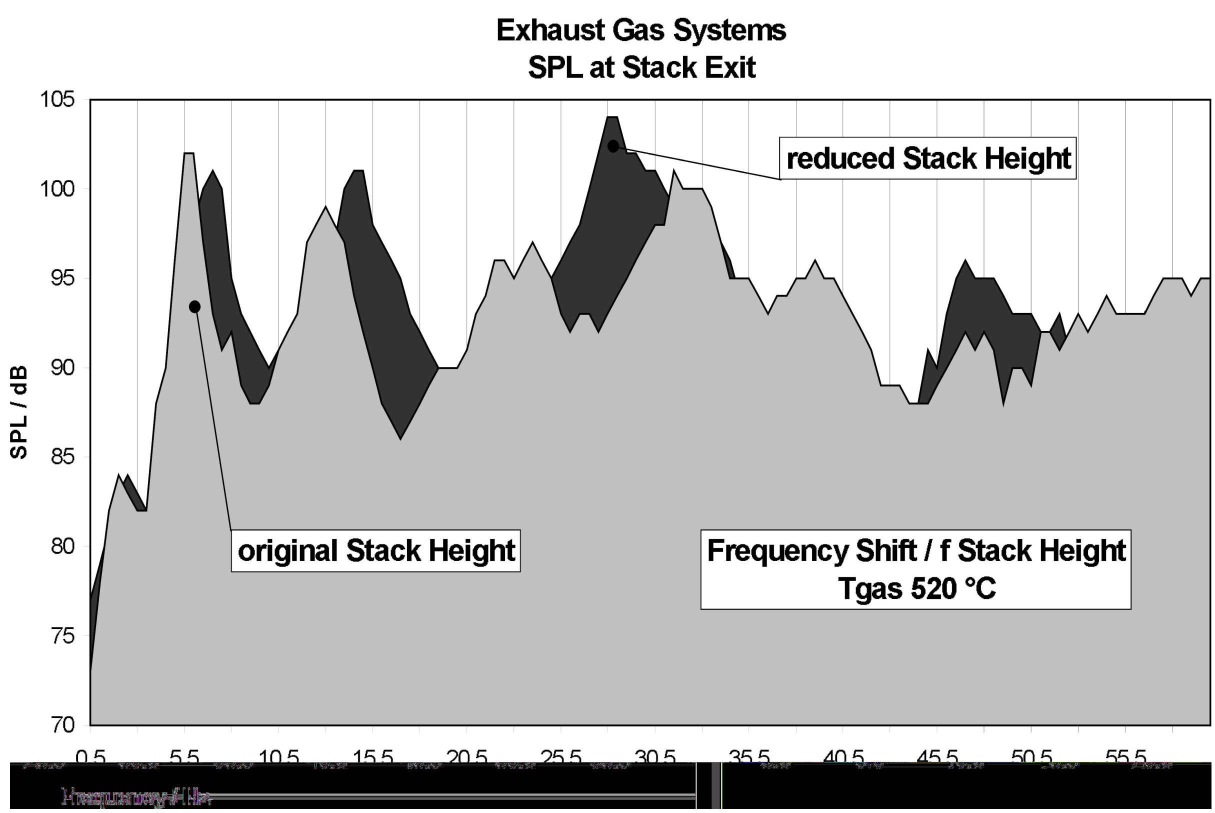

Figure 5.

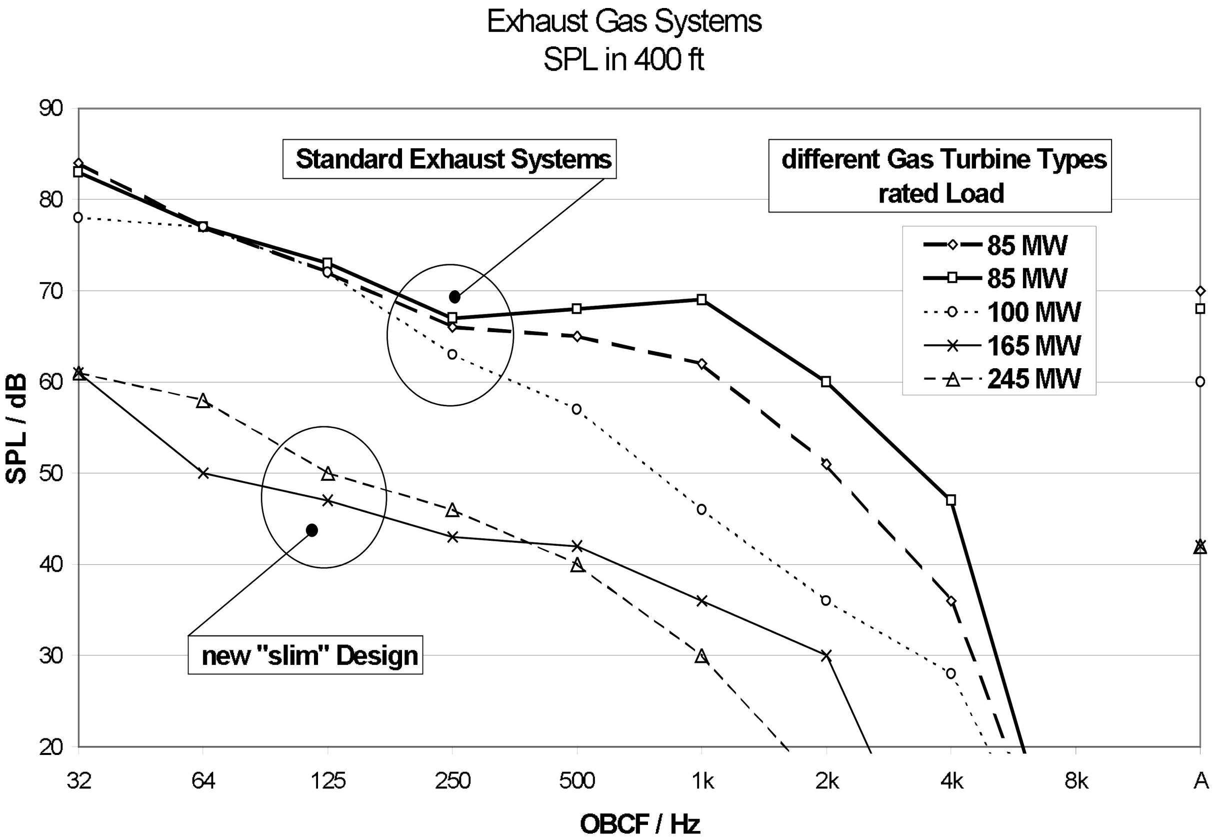

Figure 6.

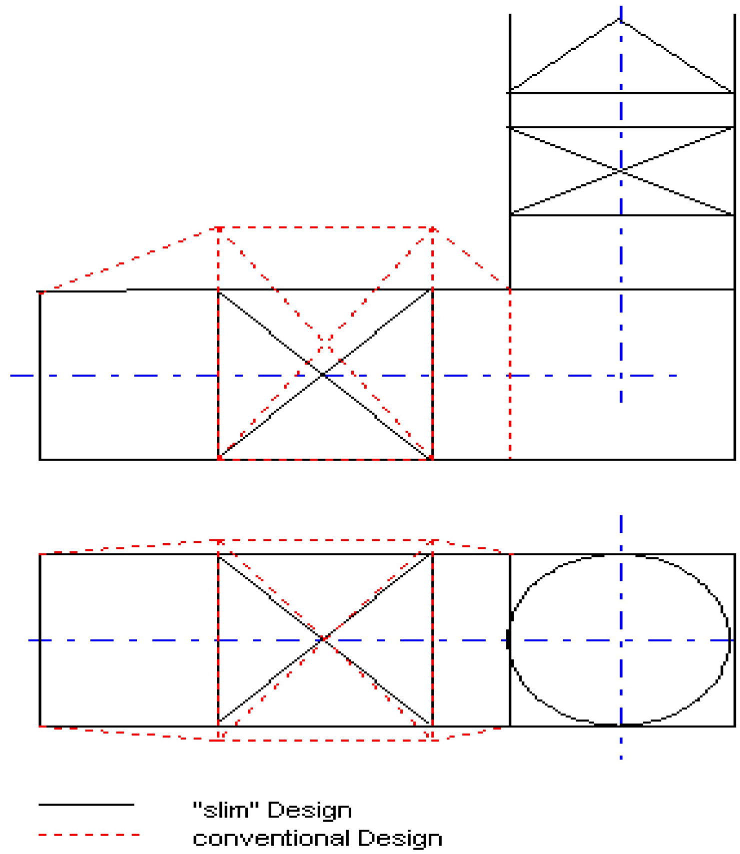

Figure 7.