Chapter IV
Results and Discussion

4.1 Sound Pressure Level Measurement of Rayong Power Plant

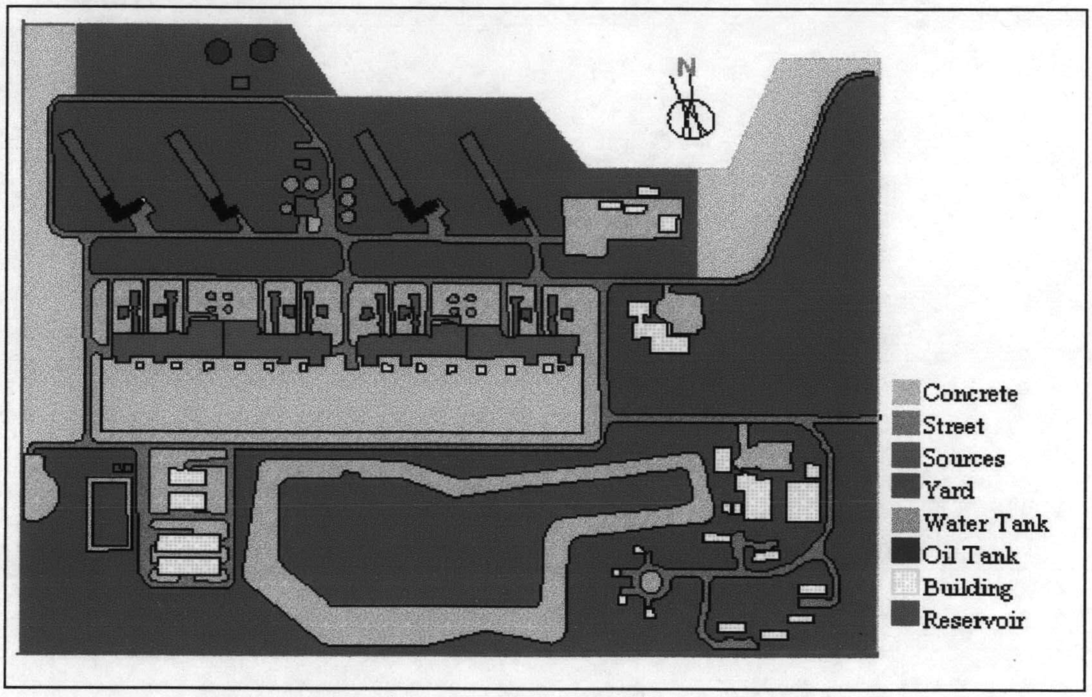


Figure 4-1 Rayong Power Plant (RPP) Plan Layout.

All of the 1/1 octave band Sound Pressure Level (SPL) measured from Rayong Power Plant (RPP) using frequency analyzer and Sound Level Meter (SLM) with octave filter set. Both equipment were calibrated at 1000 Hz with the same level by acoustic calibrator. The data were separated into 3 groups; SPL of noise source in outdoor environment, SPL inside the building, and SPL at the immission point in outdoor environment. The X-Y coordinate system presented the measured levels in 5 decibels interval by contour line method using surface mapping system Surfer version 5.01 for windows. (Golden Software, 1994) All of measurement data were presented in Appendix B. The conclusion of study result in each group are listed below:-

4.1.1 Measured SPL inside the buildings.

- Measurement positions are reported in figure 4-2
- Average SPL contour map are shown in figure 4-3
- 1/1 octave band frequencies level contour map are shown in figure 4-4 (a) to (h)

4.1.2 Measured SPL of noise sources in outdoor condition.
- Measurement position are reported in figure 4-5
- Average SPL contour map are shown in figure 4-6
- 1/1 octave band frequencies level contour map are shown in figure 4-7 (a) to (h)

4.1.3 Measured SPL at the immission point in outdoor condition.
- Measurement position are reported in figure 4-8
- Average SPL contour map are shown in figure 4-9
- 1/1 octave band frequencies level contour map are shown in figure 4-10 (a) to (h)

4.1.4 Transfer function data were considered within 1 square kilometer around the operation area of RPP. The air absorption and relative humidity were reported in table 4-1. There was slightly different about wind direction between December from north or northeast direction by prevailing wind and March from south direction by local wind. Noise data were collected outdoor depending on downwind conditions except 34 immission point along the southwestern part under upwind condition. The other parameters for transfer function input are presented in Appendix B.4. The considered transmission paths of measurements are shown in figure 4-11. Air temperature and relative humidity of air conditions at RPP were about 30^{o} C and 70% RH for the prediction model condition because temperature and humidity database have a range of 5^{o} C and 10% increment, respectively.

Table 4-1 Weather condition at RPP during the measurement.

Date	Time	Temperature (^{o}C)	Relative humidity(%)	Wind speed (m/s)	Wind direction
29 Nov1995	08:00-12:00	34	65	2	SE
	13:00-17:30	38	53	1	SW
30 Nov 1995	08:00-12:00	34	70	2	S
	13:00-17:30	33	80	2	SE
1 Dec 1995	08:00-12:00	35	70	2	SE
	13:00-17:30	31	80	1	S
2 Dec 1995	08:00-12:00	31	80	0	C
	13:00-17:30	36	60	0	C
18 Mar 1996	08:00-12:00	30	75	1	S
	13:00-17:30	31.5	65	2	W
19 Mar 1996	08:00-12:00	31	67	0	C
	13:00-17:30	30	67	1	S
20 Mar 1996	08:00-12:00	30	72	0	C
	13:00-17:30	31	71	2	S
21 Mar 1996	08:00-12:00	31	70	1	S
	13:00-17:30	31	68	1	S

Source : Haui Pong Meteorological station Map Ta Phut Rayong and on-site measurement.

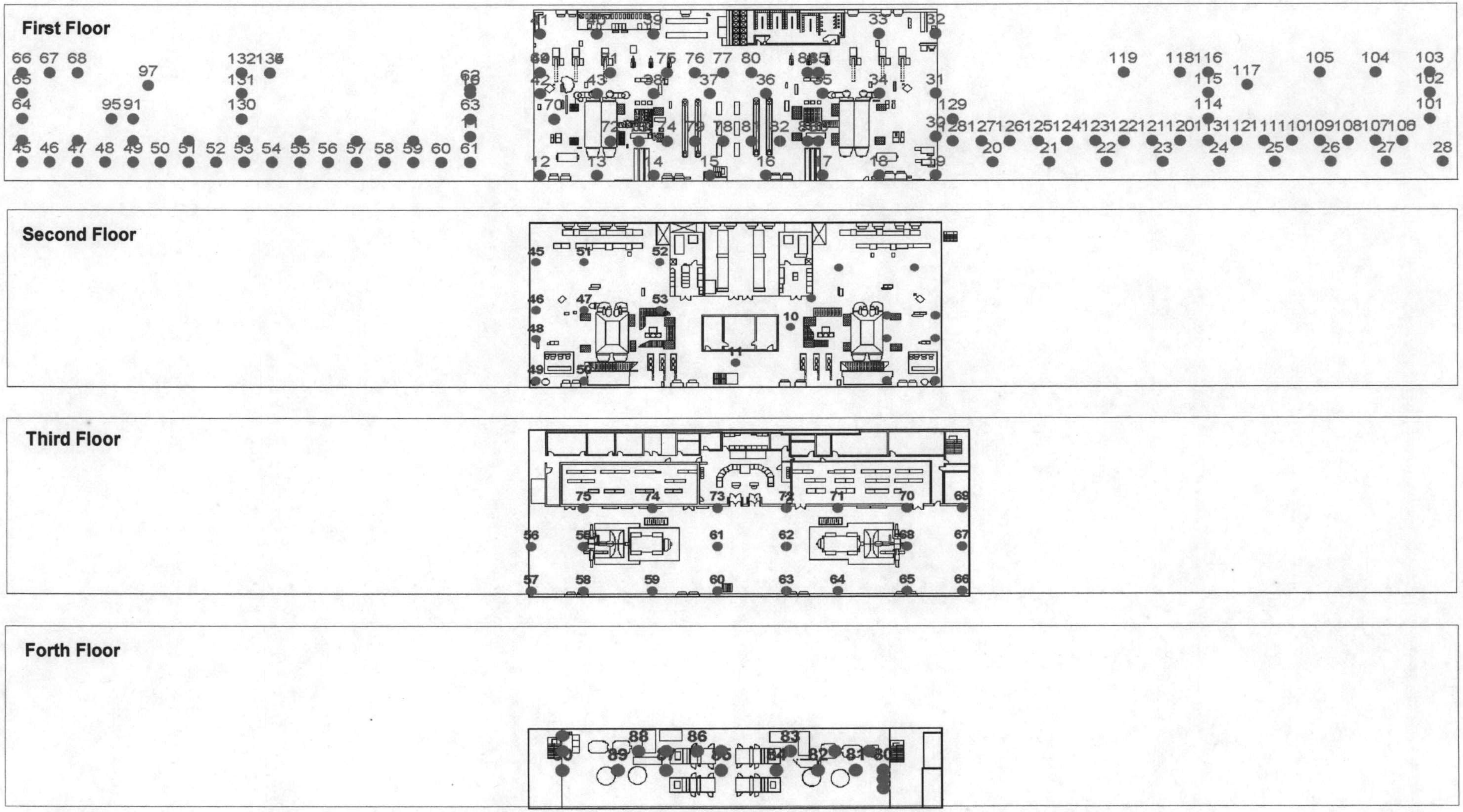


Figure 4-2 Measurement position for grid-system method inside the main building

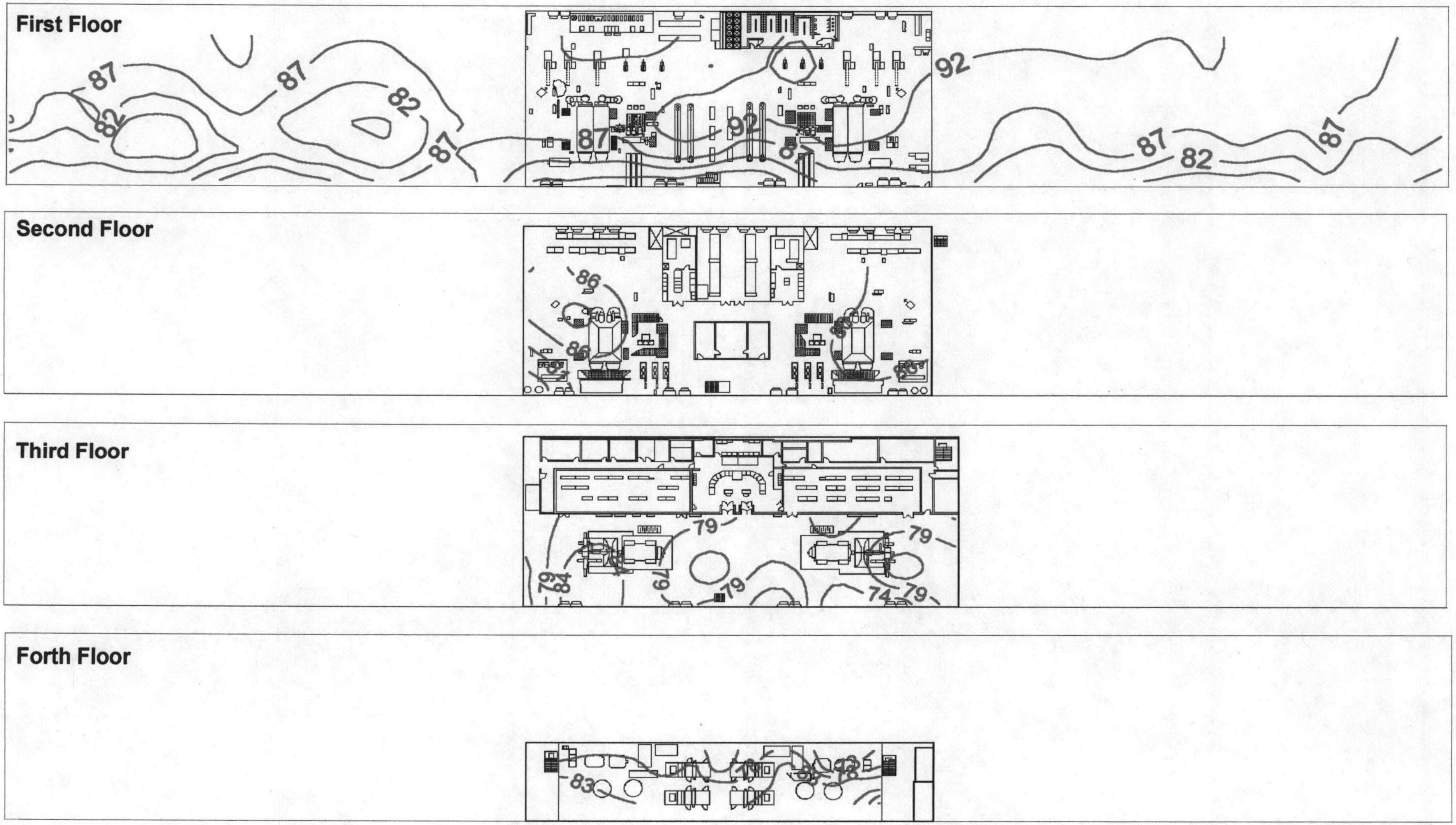


Figure 4-3 Measured SPL at node of grid box inside the main building

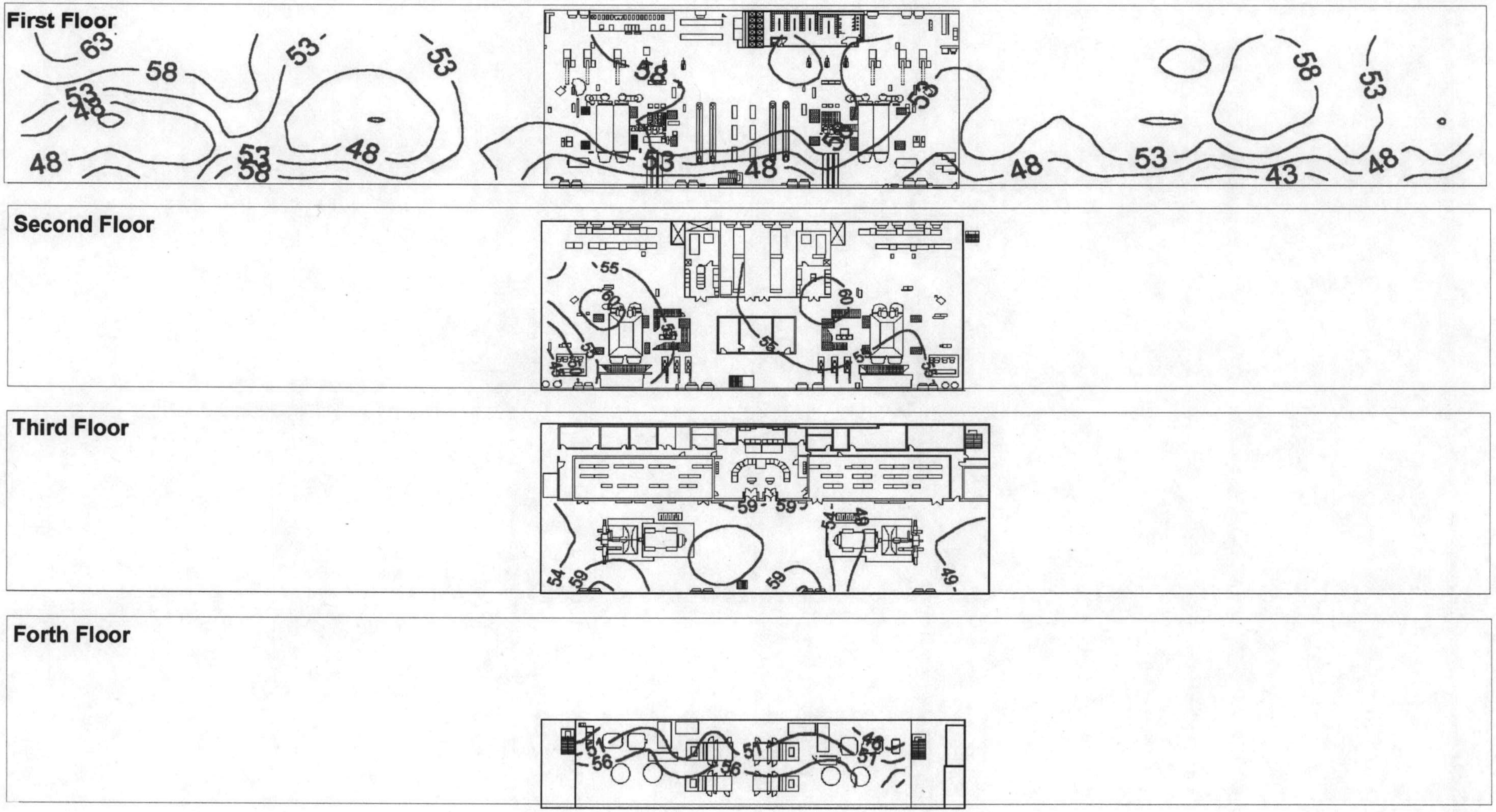


Figure 4-4 (a) 63 Hz measured SPL inside the main building

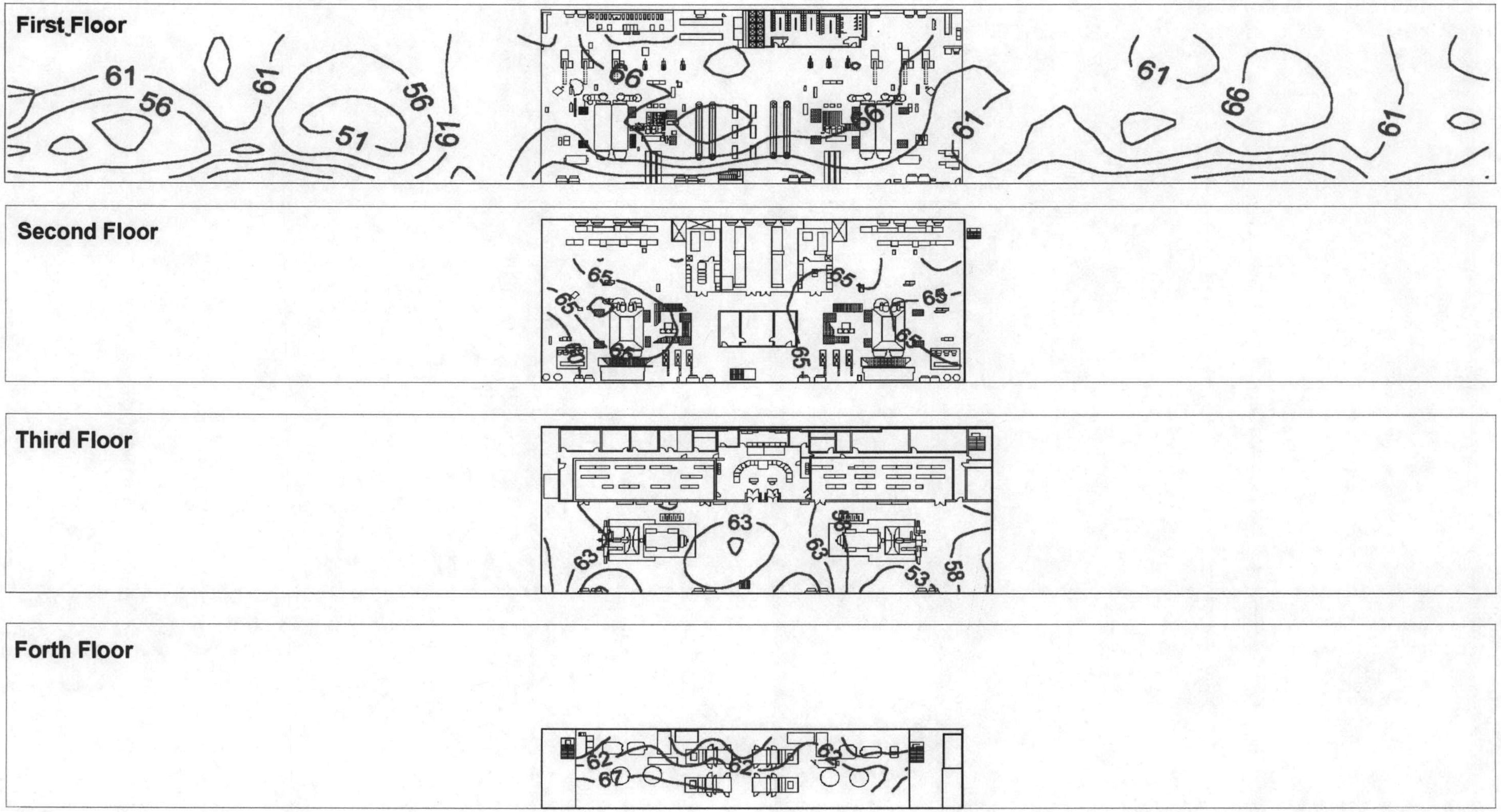


Figure 4-4(b) 125 Hz measured SPL inside the main building

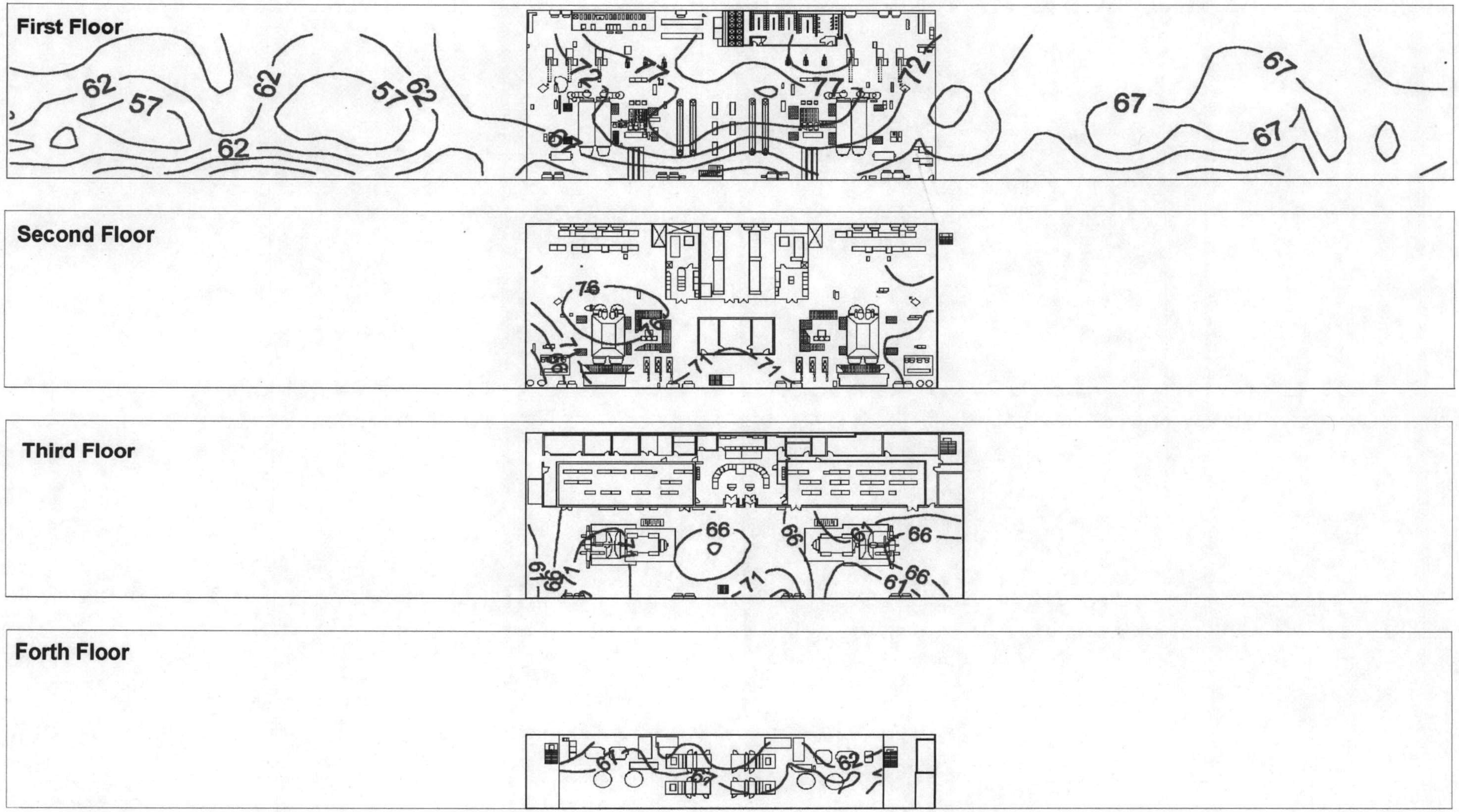


Figure 4-4(c) 250 Hz measured SPL inside the main building

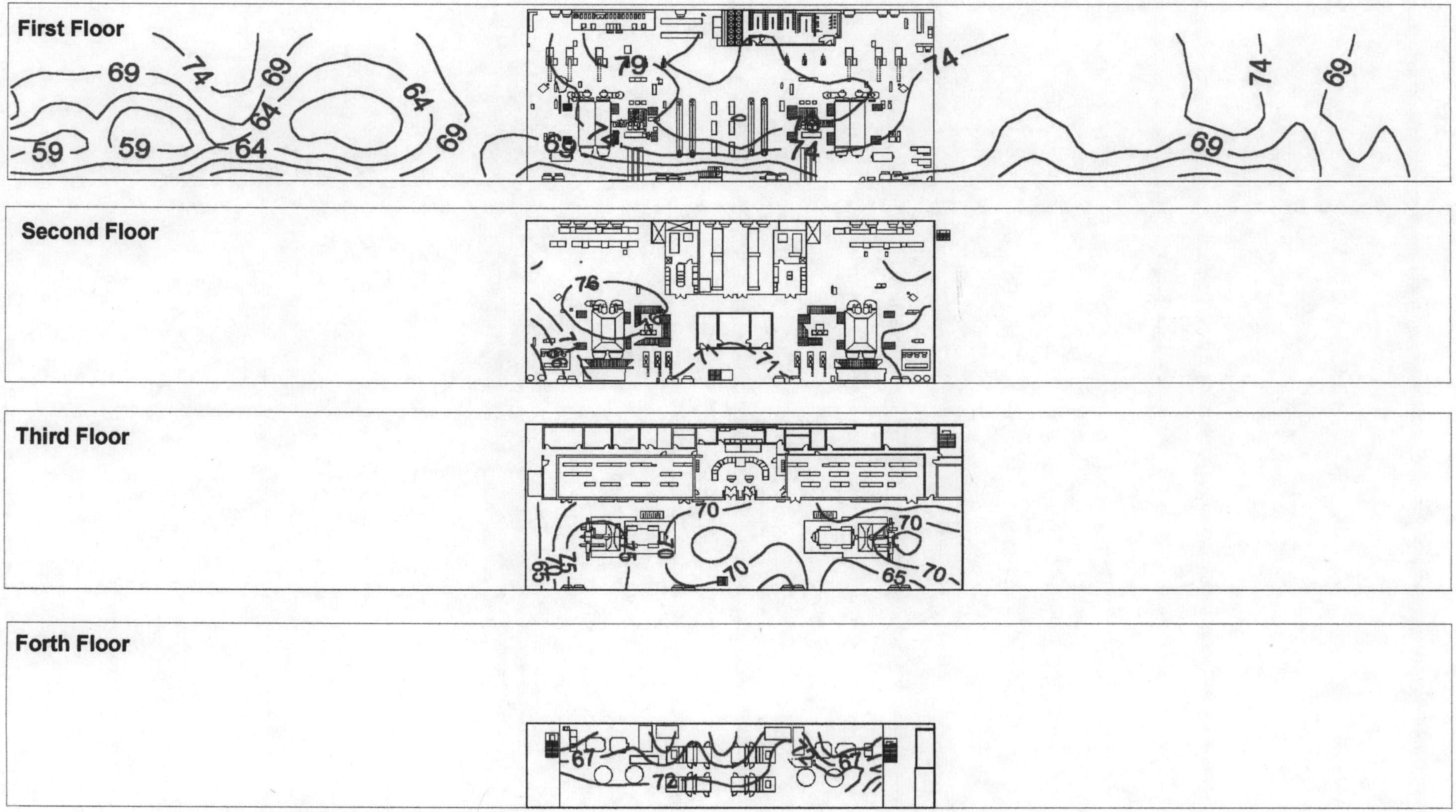


Figure 4-4(d) 500 Hz measured SPL inside the main building

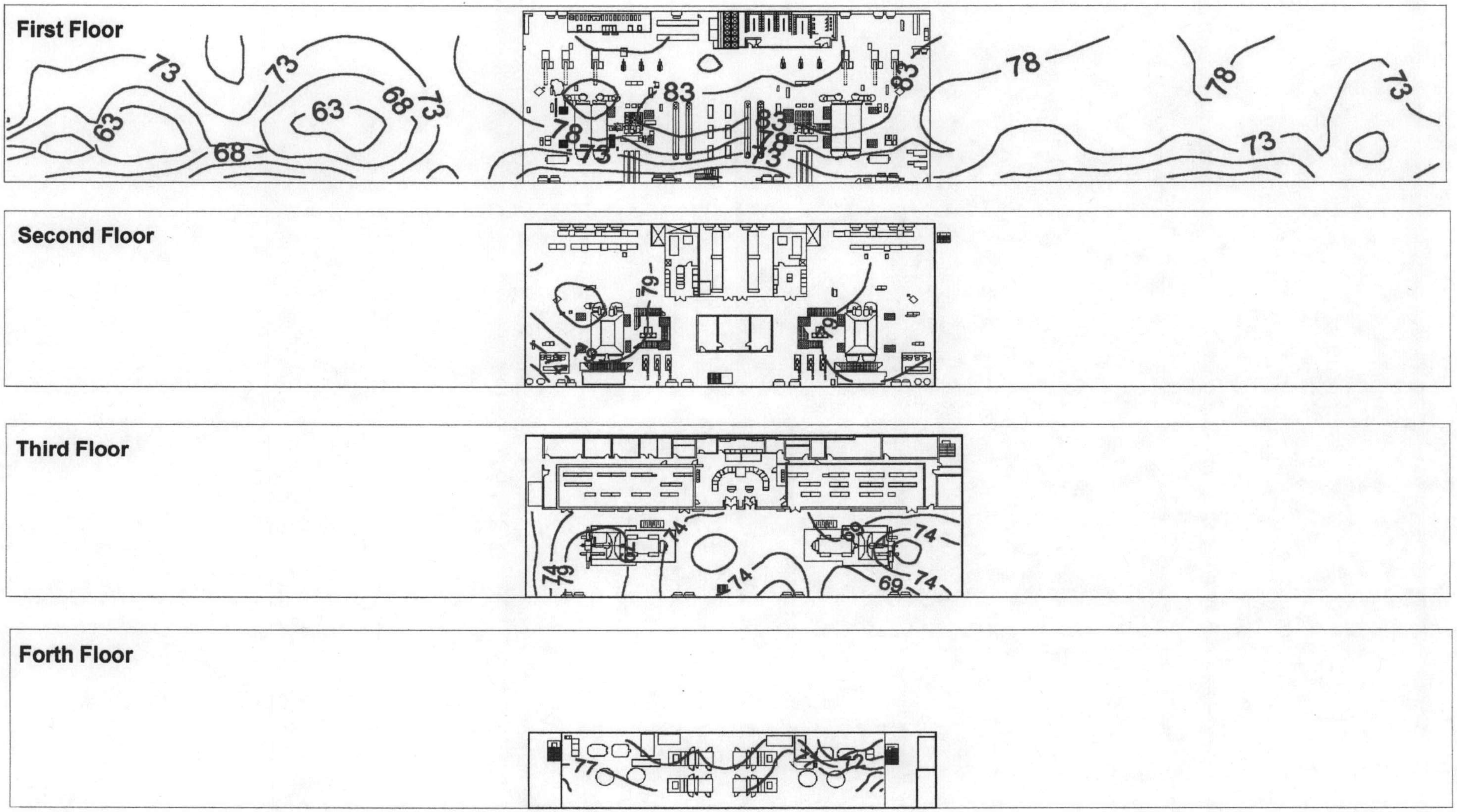


Figure 4-4(e) 1000 Hz measured SPL inside the main building

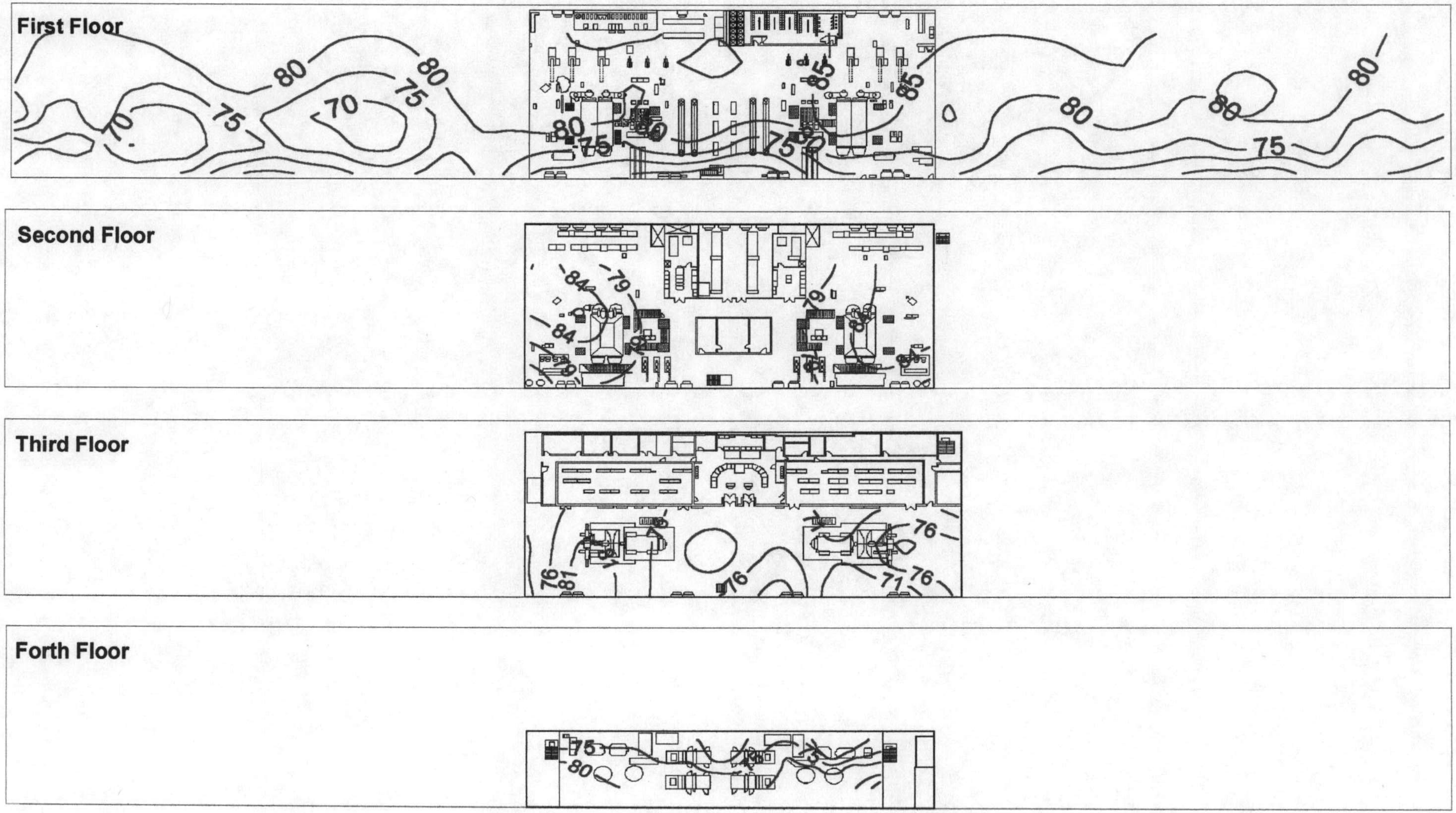


Figure 4-4(f) 2000 Hz measured SPL inside the main building

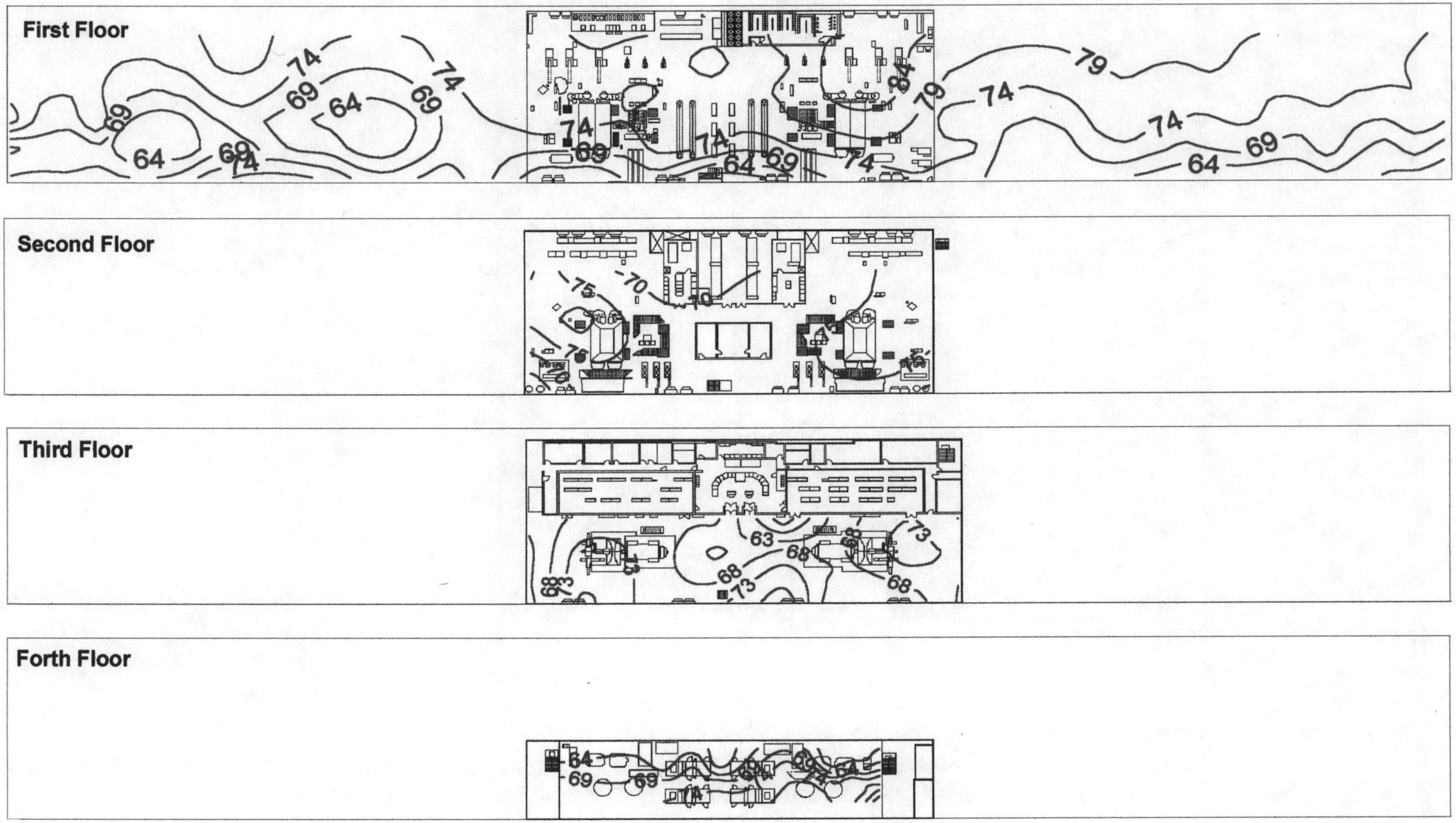


Figure 4-4(g) 4000 Hz measured SPL inside the main building

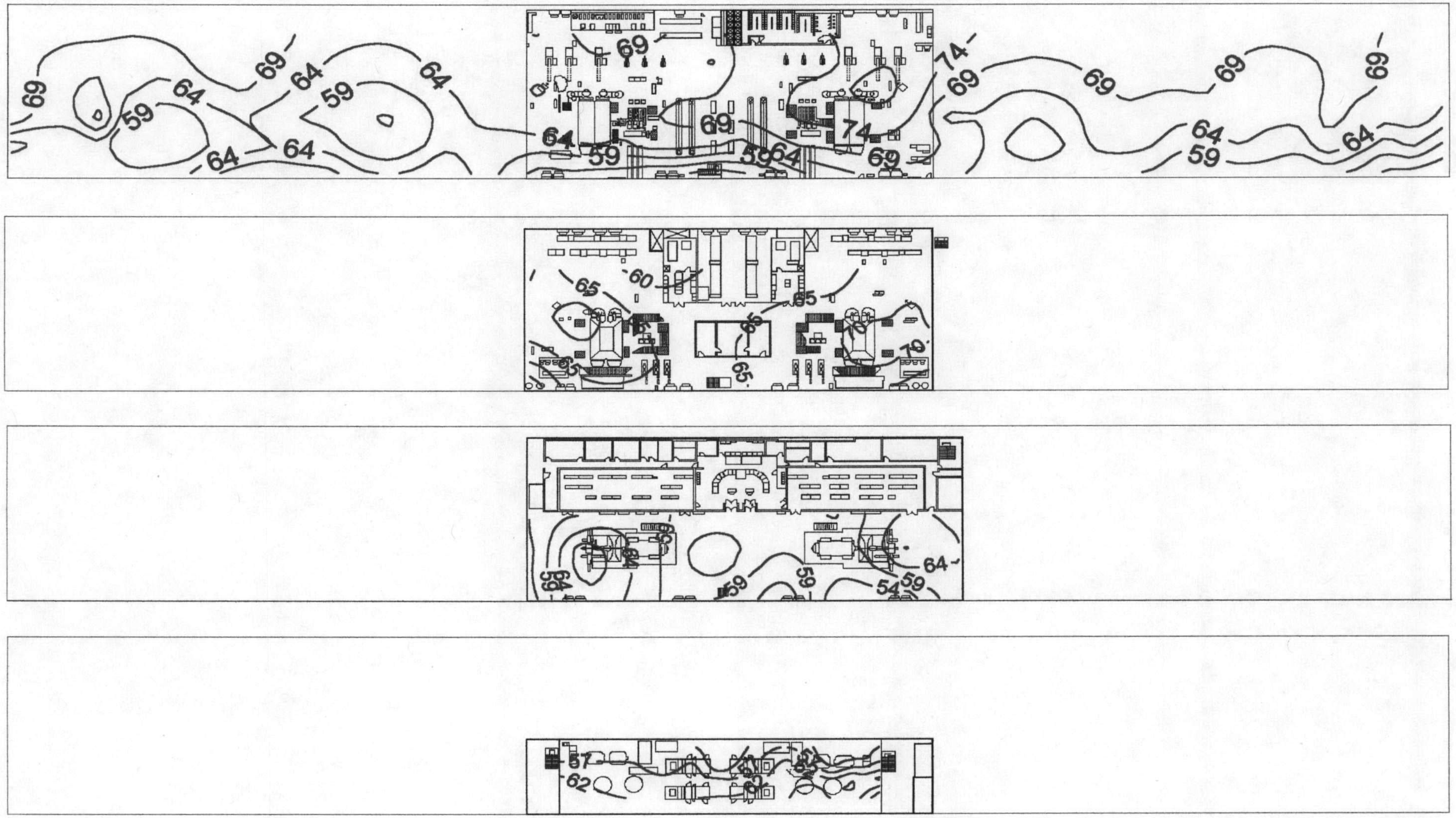


Figure 4-4(h) 8000 Hz measured SPL inside the main building

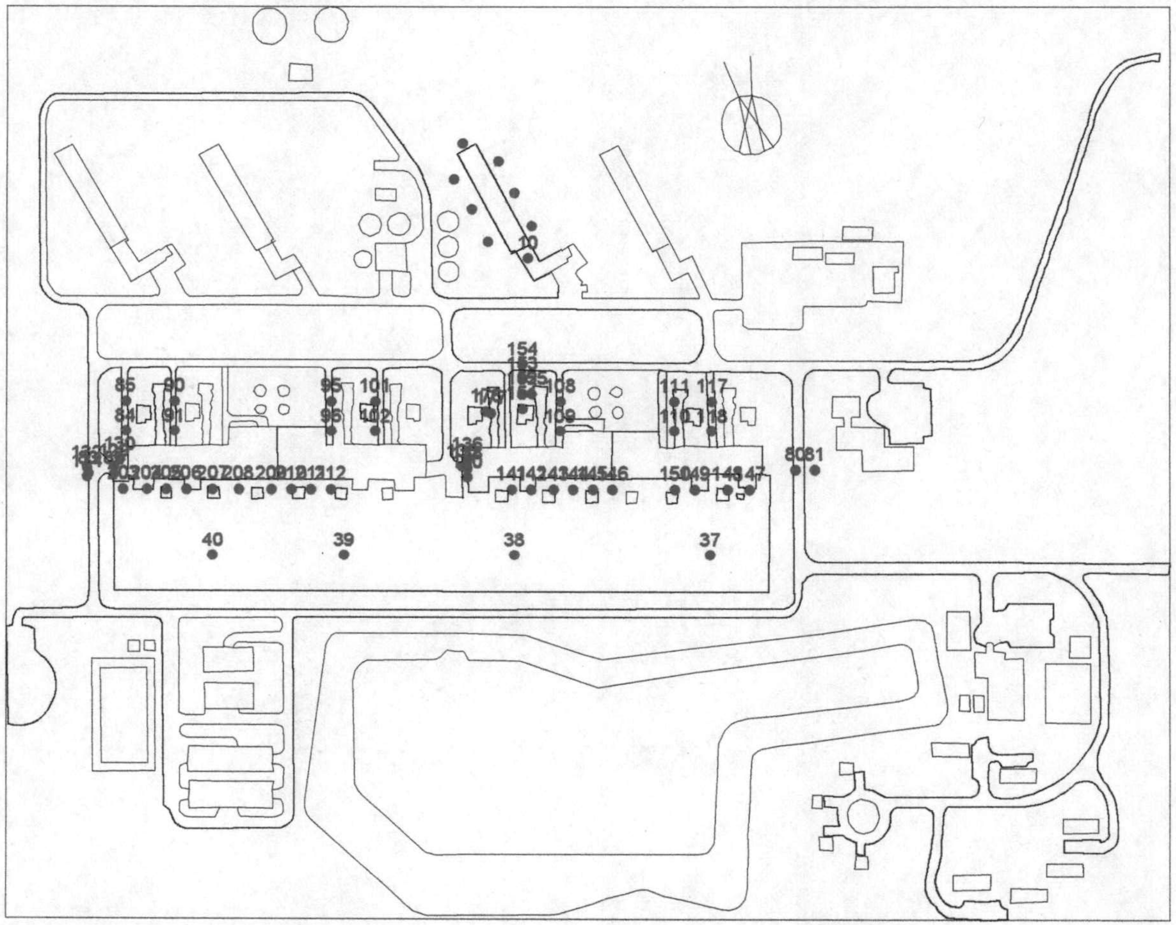


Figure 4-5 Measurement point of measured SPL for noise source

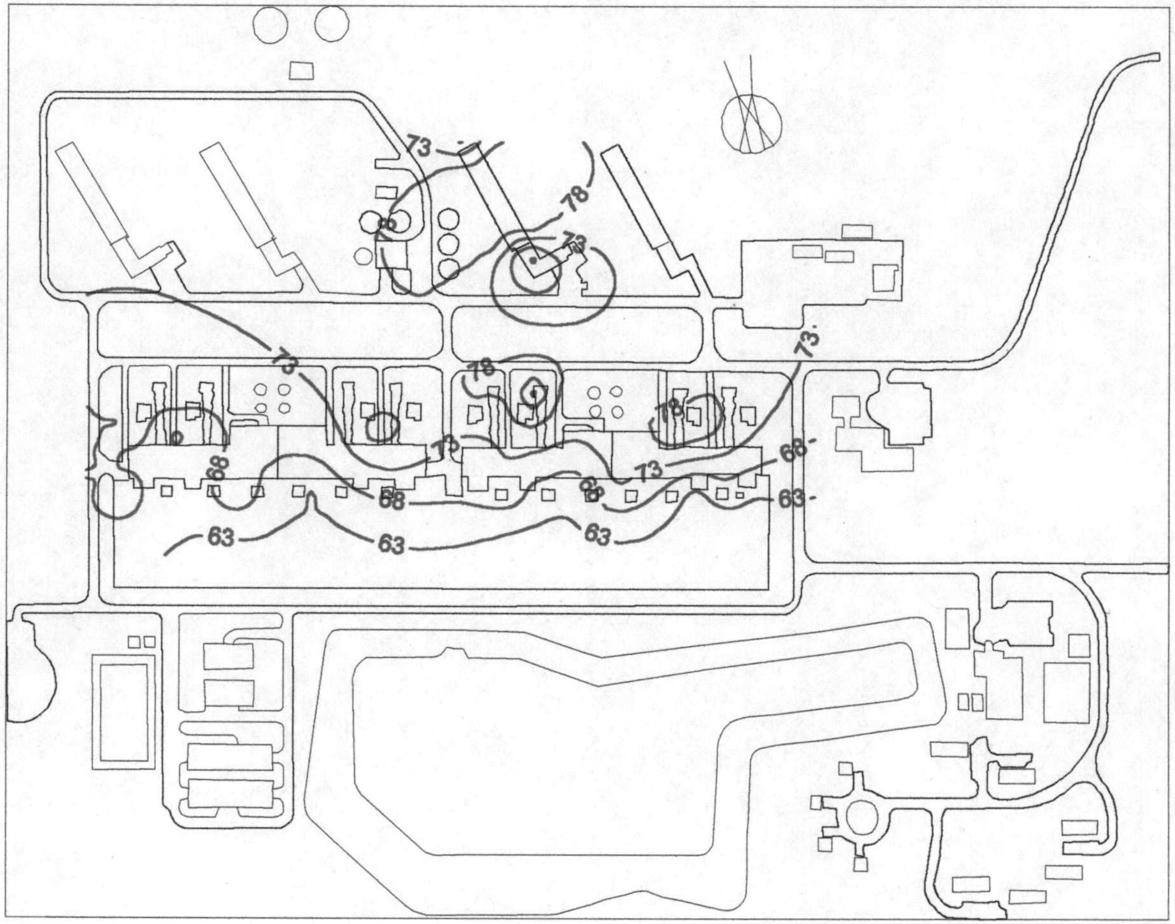
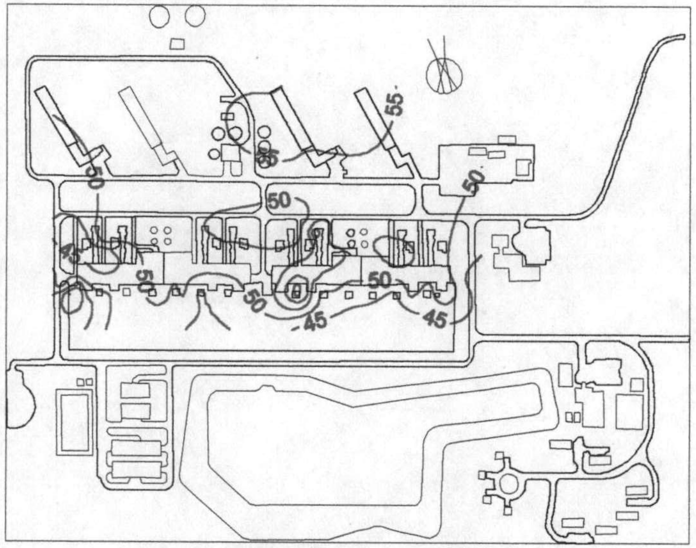
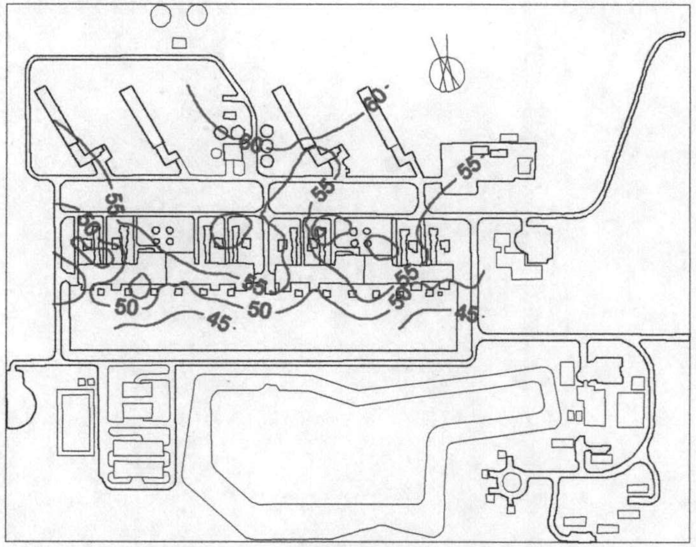


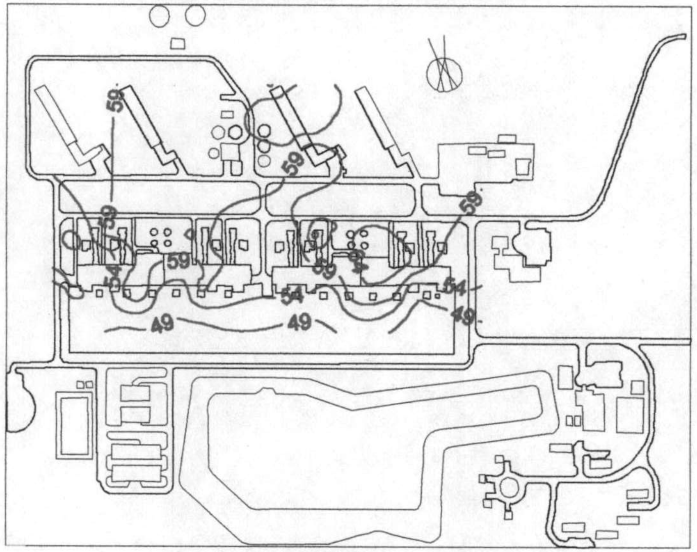
Figure 4-6 Contour map of measured SPL for noise source determination



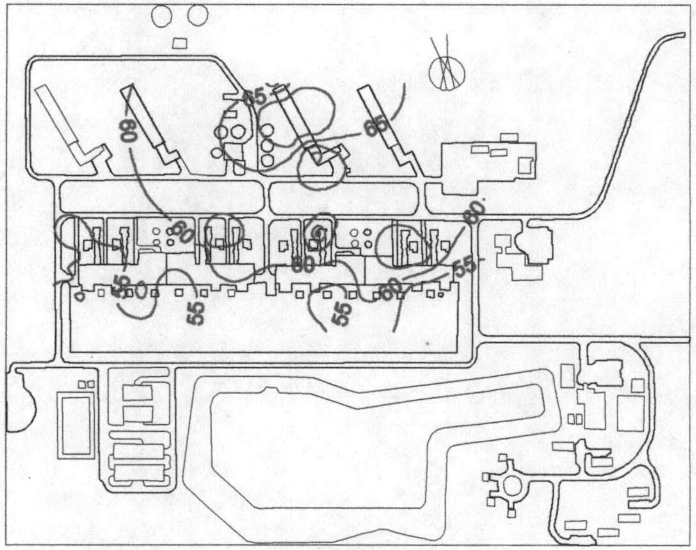
(a) 63 Hz



(b) 125 Hz

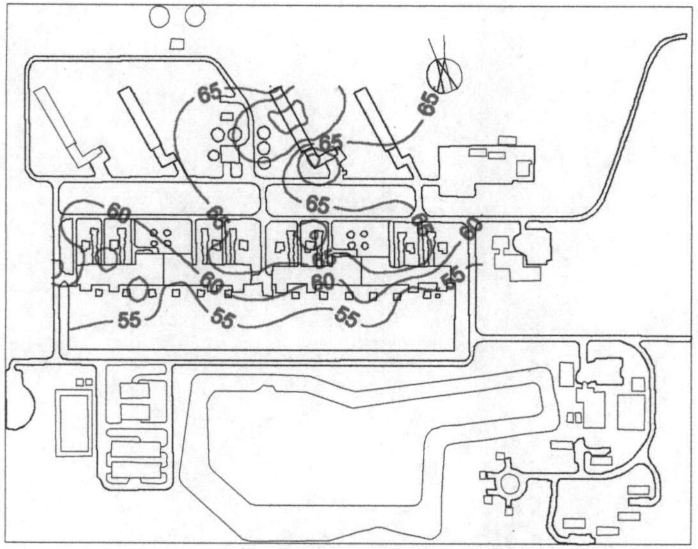


(c) 250 Hz

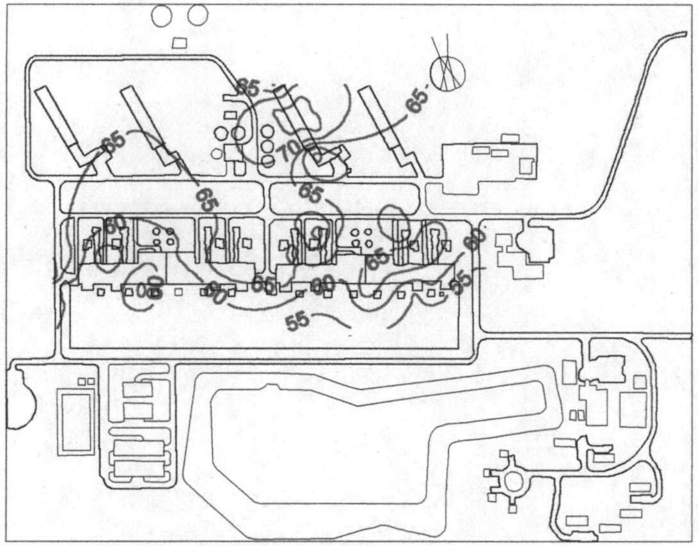


(d) 500 Hz

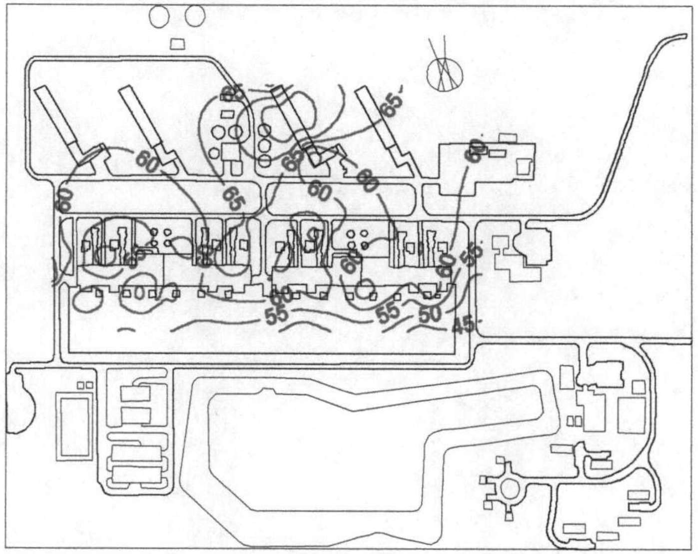
Figure 4-7 (a) to (d) 1/1 Octave band measured SPL for noise source determination



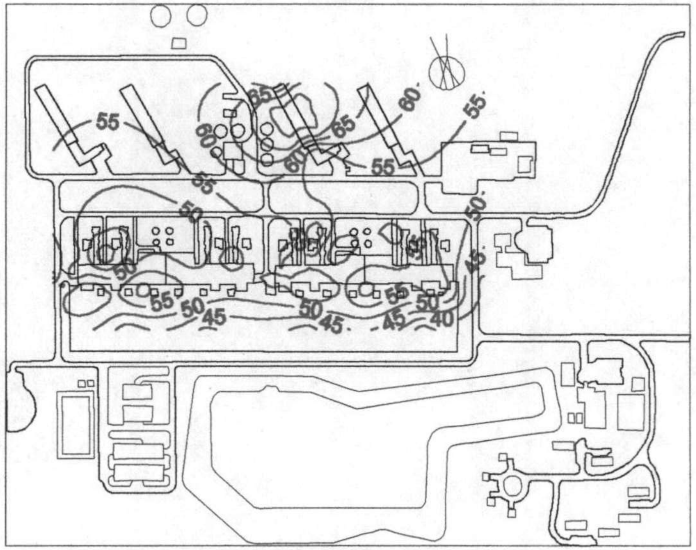
(e) 1000 Hz



(f) 2000 Hz



(g) 4000 Hz



(h) 8000 Hz

Figure 4-7 (e) to (h) 1/1 Octave band measured SPL for noise source determination

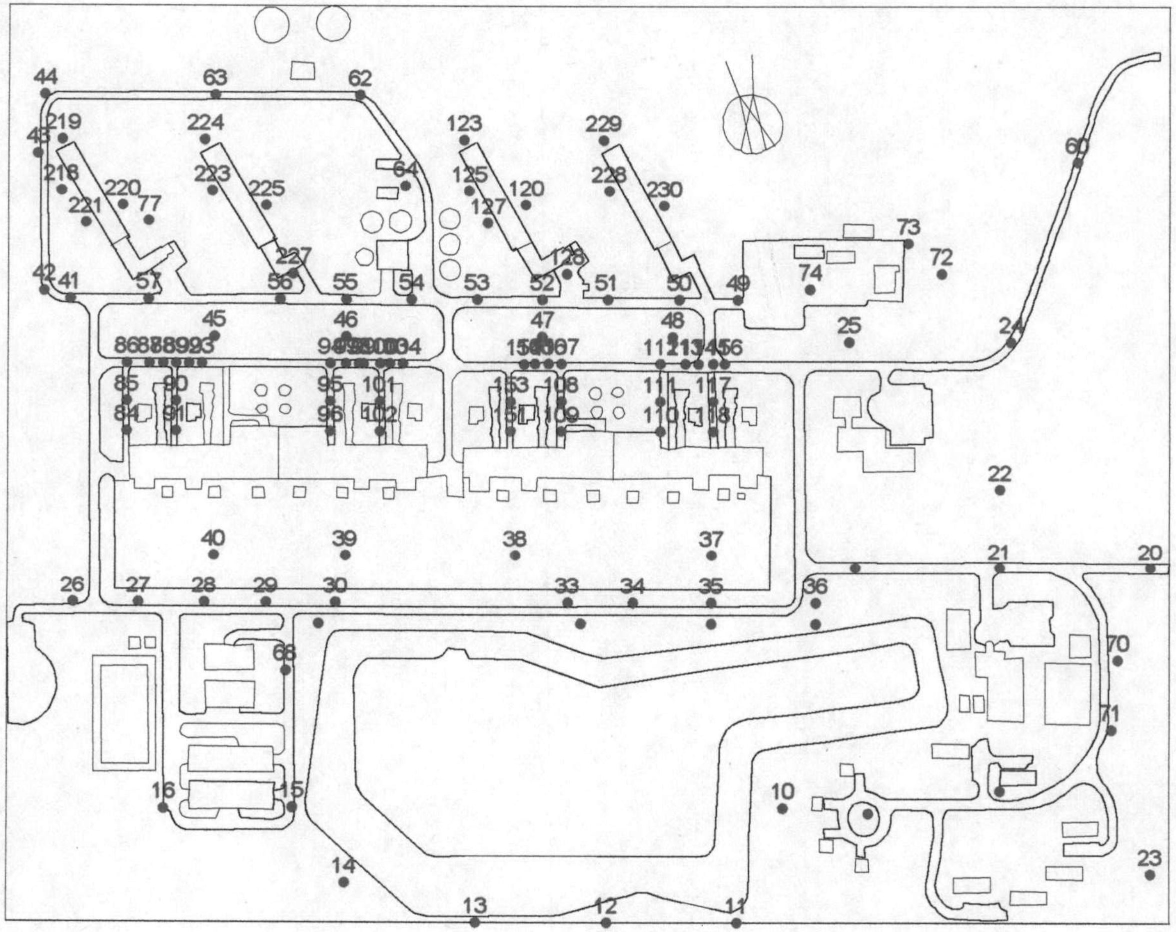


Figure 4-8 Measurement point of measured SPL at immission point

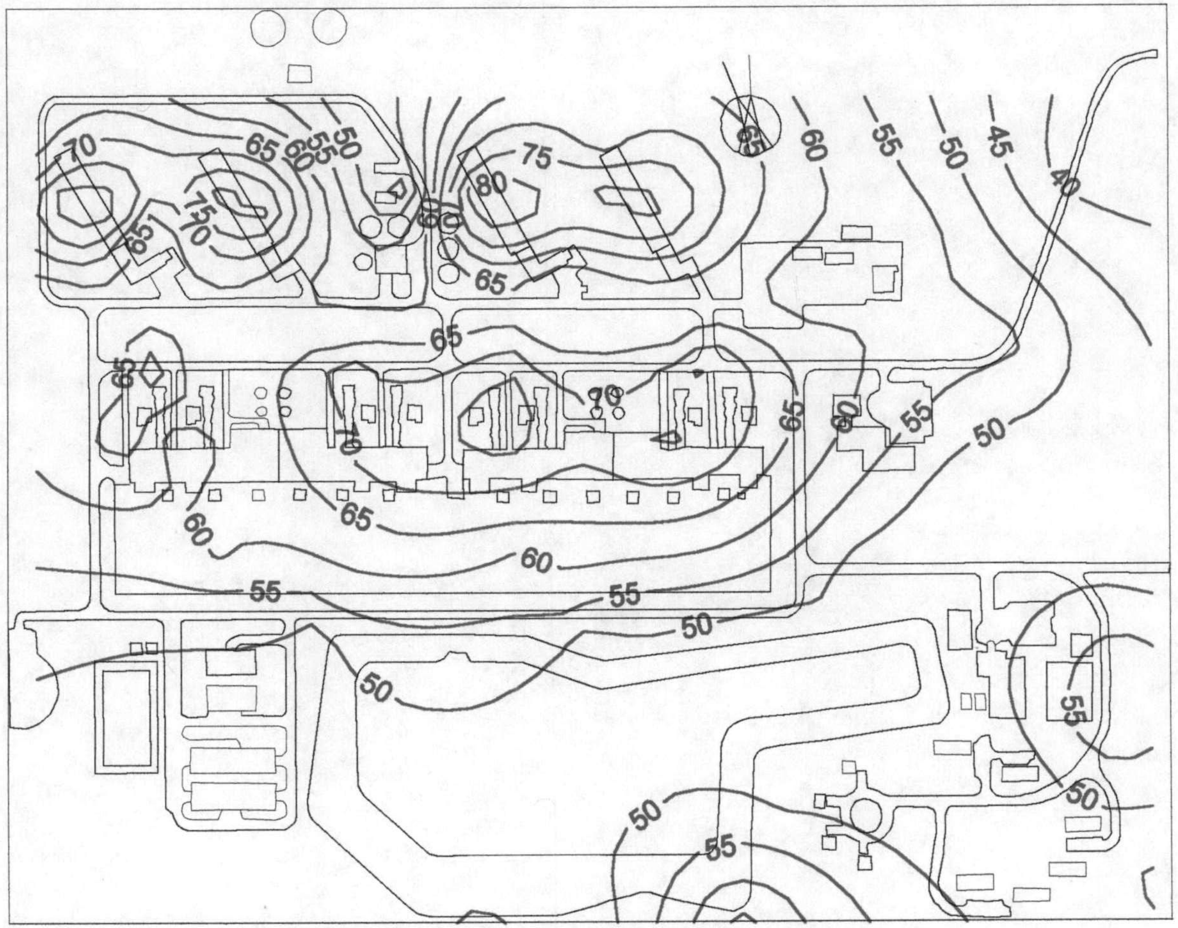
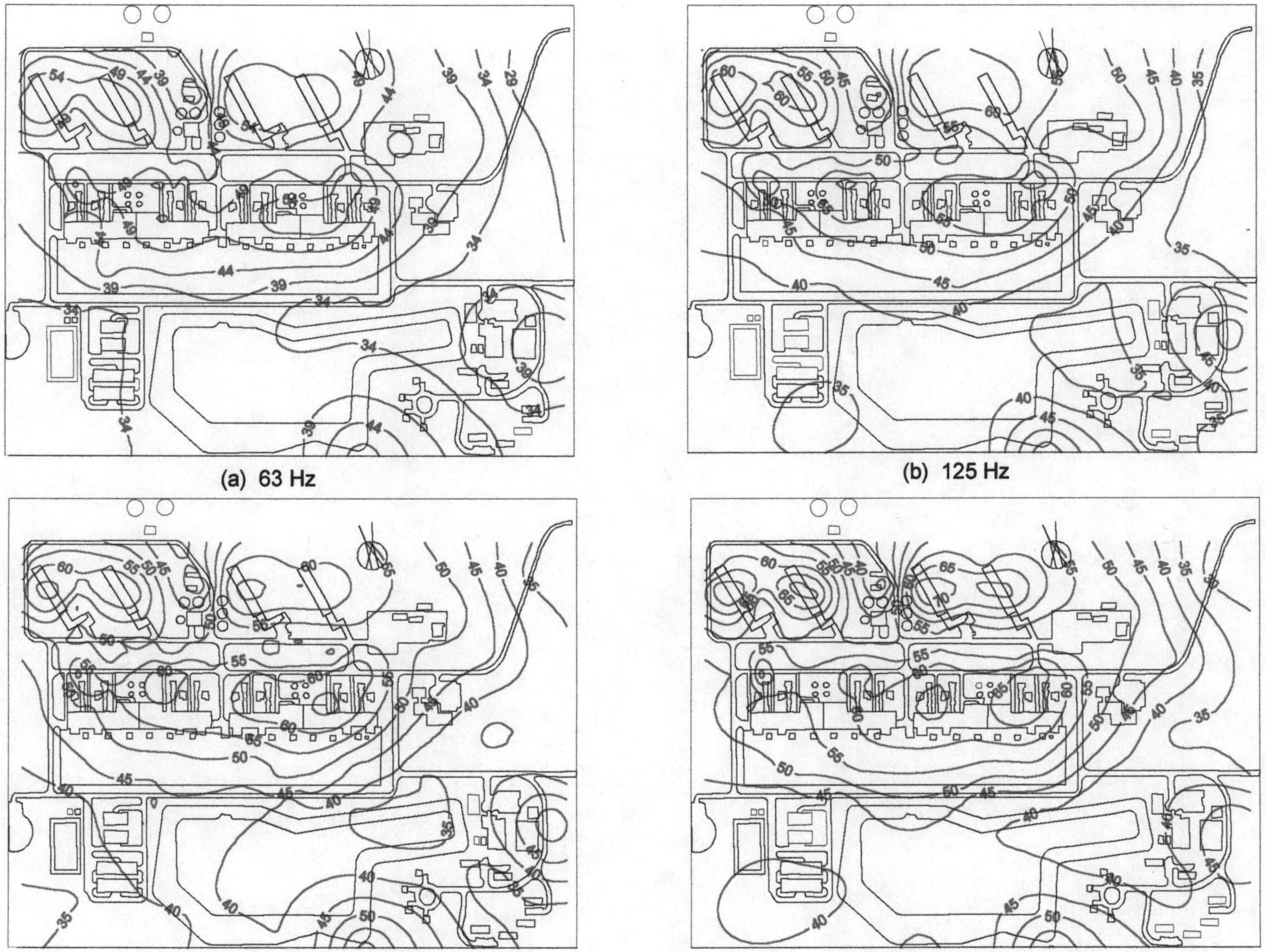


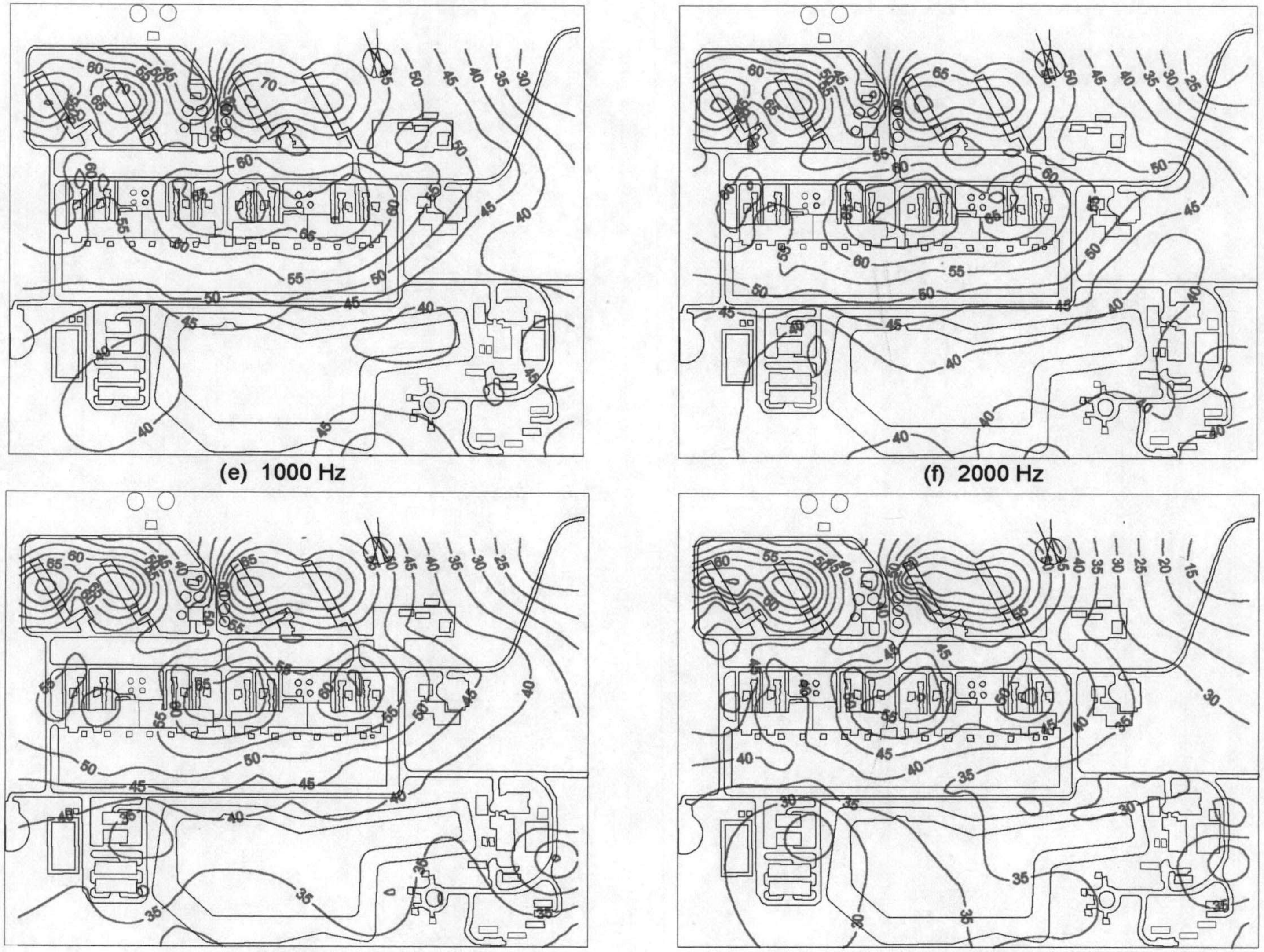
Figure 4-9 Contour map of measured SPL at immission point



(a) 63 Hz (b) 125 Hz

(c) 250 Hz (d) 500 Hz

Figure 4-10 (a) to (d) Contour map of measured SPL at immission point



(e) 1000 Hz

(f) 2000 Hz

(g) 4000 Hz

(h) 8000 Hz

Figure 4-10 (e) to (h) Contour map of measured SPL at immission point

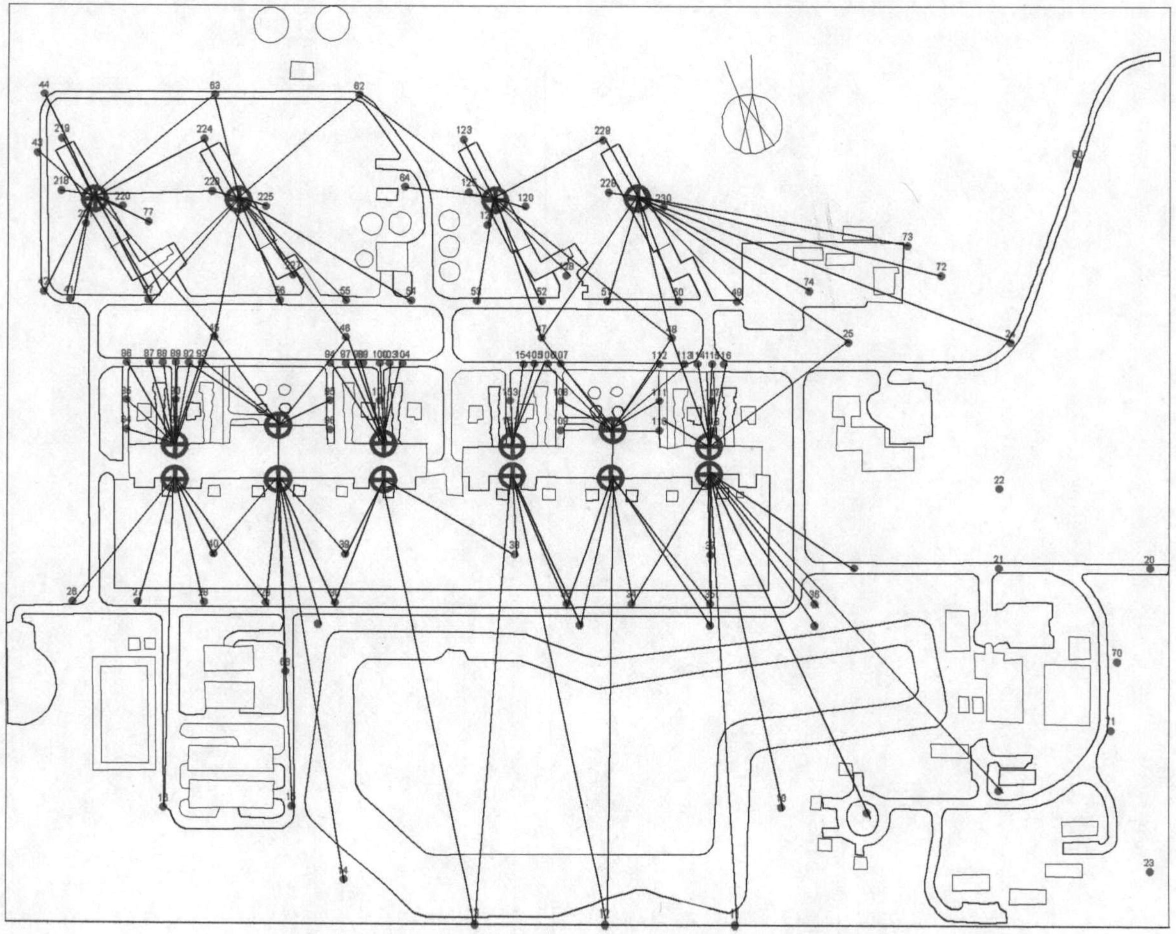


Figure 4-11 Transmission paths for noise prediction model

4.2 Calculated Sound Power Level of Noise Sources

RPP continuously operates at a constant capacity. Typical noise sources are combustion air inlets, air inlet cleansers, electric motors, Gt., STs, HRSGs, electric fans, condensers, pumps, storage tanks and pipelines. RPP was designed to meet the international industrial noise limit at work. (Shell Internationale Petroleum MIJ.B.V., 1993) Therefore the enclosure wall were built to cover almost main noise sources in order to control the noise levels. These installations take advantage in low cost for noise control in factories. (Johnson, 1995) Machinery were designed to be installed inside the enclosure wall to prevent the high noise levels from typical sources such as GT, ST, condensers, generators, feed pumps to the environment. Some sources are located outside the enclosure wall such as water pumps, feed pumps, cooling fin fan, electric motors, and air inlet cleanser.

The explanation of sound sources are in table 4-2 and 4-3. SPL of GT, ST, and condenser inside and outside the enclosure wall inside the building were shown in table 4-4. The enclosure wall made from steel sheet with mineral wool lining each of which had a different thickness between adjacent sheets. From indoor measurement, noise characteristic of combined cycle system is broaden in range of frequency. High frequency components were resulted by blade passage of the compressors and turbine. Low frequency components become from the combustion process and exhaust flow. Measured SPL inside the enclosure room showed an outstanding high levels at 100 to 125 Hz. It might be caused by the attached absorbing materials. Thus, large building contained noisy machines with acoustical absorption attached to the inner wall were one of the important sources of RPP. The other important sources are cooling tower. The measured SPL of all RPP's sources, used for determining PWL of those sources were in Appendix B.1.

From the observation, RPP operation areas have two main sources; cooling towers and main buildings being large sources. The noisy machines of RPP are mostly situated inside large building with specific acoustic absorption material. The other sources are small or sources. Mechanical induced cooling tower generated noise from fan driven motor, fan noise, water pumps and splashing water. Main building generated mixed noise from multi-source such as GT, ST, transformer, condenser, compressor, furnace, gearbox, electric motor, diesel engine, pumps and pipeline system. There are enclosure wall and specific insulator covering main noise source of the combined cycle unit.

The considered sound source of RPP were calculated by the proposed determination method in section 2.5.2.1. The calculated PWL of those sources were presented in table 4-5 (a) to (e). The different type of noise sources were considered by the dissimilar methods. The author advised a selection criteria for PWL determination of the chosen sound sources for this prediction model in the following paragraph.

Table 4-2 Noise sources, located inside plant's enclosure.

Name of noise source	Type	WxLxH (m.)	Mechanical power(KW)	Numbers
combustion gas turbine 1)	type 9001E	20x5.5x7	-	8
Generator main circuit 2)	Low-Medium voltage and switchgear	-	-	8
Diesel engine	-	-	-	8
Air inlet with electrostatic precipitator	-	-	-	8
Steam generator feeding Pump	-	-	75	12
Chemical feeding pump	-	-	0.37	32
Steam generator motor	-	-	990	12
Condenser 3)	-	15x10x10	-	4
Steam generator Submerged pump	-	-	-	12
Fluid motion in pipeline	-	-	-	-
Air-conditioned compressor units	-	-	-	8
Steam Turbine	-	10x19x4	-	4

*1. Gas Turbine System

They used combustion gas turbine type 9001E which are separated to four parts. There are produced noise from fluid flow in ducts, rotating blade of gas turbine engine, generator, and other accessory equipment such as pump, motor.

1.1 Control Compartment or Local control room consists of control equipment such as turbine control panel, generation control panel, generator protective relay panel and motor control center (MCC)

1.2 Accessory Compartment consists of main parts, small parts, mechanical and electrically equipment for starting up and operating system.

1.3 Turbine Compartment consists of compressor/turbine that concluded inlet duct and exhaust plennum/ducting.

1.4 Load Compartment consists of turbine and generator coupling.

*2. Generator main circuit system

2.1 Low voltage : APC-416 V, APA-240 V, API-230 VAC and 250 VDC, APH-125 VDC

2.2 Medium voltage : APE-6.9 KV, APK-6.9 KV There are four parts of switchgear;

APE SWG 1 is the switchgear that charges of Gas turbine. Its 2 ways charges for reserve auxiliary transformer(RAT) and black start diesel.

APE SWG 2 is the switchgear that charges of Steam turbine at starting up stage by SWG 1 and then receiving from main aux. transformer.

APE SWG 3 is switchgear that acts like APE SWG 2

CAPK SWG 1 (Emergency diesel switchgear) use power source from black start diesel start up for supplying voltage black-out of APE SWG 1 .

*3) Condenser parts is a part of steam generator system. They are the noisiest machine in side the enclosure of plant in case of closed combined cycle power plant. The source of noise came from steam flow inside the condenser duct.

Table 4-3 Noise source, located outside plant's enclosure.

Name of noise source	Mechanical Power (KW)	Length (m.)	Width (m.)	Height (m.)	Numbers
Heat Recovery Steam Generator 1)	-	14	45	30	8 sets
Cooling fin fan 4)	132 per set	12	11	7.5	8 sets
Ventilation fan	15	-	-	-	128
Air inlet with electrostatic precipitator 3)	-	5	5	5	8
Cooling fin fan motor	75	-	-	-	16
High pressure motor	990	-	-	-	16
Low pressure motor	61	-	-	-	16
Mechanical induced-draft 2) cooling tower	-	85	15	15	4
Cooling fan motor	132	-	-	-	20
Cooling submerging pump	900	11	2.5	5	12
Fluid motion in pipeline	-	-	-	-	uncounted
Air-conditioned units	-	14.2	6.2	1.8	2 sets

*1) Heat Recovery Steam Generator Type CMI

Waste Heat Recovery Boiler Two Pressure (Dual press) complete system, leads exhaust gas from combustion turbine to heat for input boiling water to steam turbine. First, water from deaerator that was pumped by HP-Boiler feed pump to HP-1 economizer inlet header and go through Eco.coil for increasing water temperature before input to boiler drum. Hot water from boiler drum go through boiler water circuiting pump(BWCP) for evaporator coil circulation. Its return to boiler drum by separator after evaporating for separate steam out of water. The steam will go through superheat coil for adjusting exhausted temperature.

*2)Cooling Tower parts

Mechanical Induced-Draft cooling tower has noise source from two parts as belows;

2.1 Noise from Spraying Water

2.2 Motor for cooling fan

*3) Air-Inlet Parts

The air get through the electrostatic precipitator plenum that hanged 10 meters above the wall of building ,produced noise from air-flow inside duct.

*4) Cooling fin fan Parts

There are 8 sets of cooling fin fan beside the HRSG on the ground and it has 12 units-fan per sets.

Table 4-4 Comparison of measured SPL inside and outside enclosure room.

Machine	Status	1/1 octave band SPL, dB								
		63	125	250	500	1000	2000	4000	8000	ALL
Gas Turbine	inside	55.7	65.1	78.1	83	84.2	87.2	85.9	97.7	93.1
Gas Turbine	outside	**58.5**	61.9	66.6	69.2	71.7	84.5	76.7	71.2	85.7
Steam Turbine	inside	56.2	62.6	75.1	83.1	87.1	86.4	79	75	91.1
Steam Turbine	outside	55.8	**65.1**	69.6	72.7	75.6	78.6	73.1	65.5	82.1
Condenser *	-	64.9	72.6	81.3	82.8	87.8	90.1	83.3	74.4	93.5
Reduction of GT enclosure wall	-	2.7	3.2	11.5	13.8	12.5	2.7	9.2	16.5	-
Reduction of ST enclosure wall	-	0.4	2.6	5.5	10.4	11.4	3.8	5.9	10.5	-
TL -Building wall	-	6.1	6.4	10.8	9	14.1	21	21.7	20	-

Remarks: inside = inside enclosure room

outside = outside enclosure room

* Condenser without enclosure room

BOLD : small source outside the enclosure room close to measurement point.

Table 4-5 (a) Point source PWL in decibel

Machine	1/1 octave band PWL in dB								PWL dB
	63	125	250	500	1000	2000	4000	8000	
Cooling Tower	63.2	66.5	67.7	72.4	74.2	74.3	74.9	73.5	81.3
Cooling Fin Fan	48.5	52.8	53.5	57.5	63.7	61.3	55.5	45.4	67.1
HP/LP HRSG Motor	36.2	36.2	49.1	59.0	62.1	59.3	52.5	42.9	65.5
CFF Motor	56.8	59.3	65.3	75.0	81.0	78.8	73.0	62.9	84.1
Air Compressor Unit	53.7	58.3	77.7	74.3	73.1	72.6	64.3	57.4	81.1
Opening shutter*	46.7	56.7	60.0	54.7	55.3	56.4	52.7	44.2	64.4
Air Inlet *	74.8	80.5	88.3	94.2	95.7	97.7	96.0	83.7	102.3
Submerged Pump	48.7	54.5	52.3	58.1	66.5	65	57.7	50.3	69.8

* Calculated by equation (a) and (c) respectively from table 2-13

Table 4-5 (b) PWL in decibel by Colenbrander method.

Machine	1/1 octave band PWL in dB								PWL dB
	63	125	250	500	1000	2000	4000	8000	
Cooling Tower	93.8	97.5	100.4	106.8	109.4	109.9	110.5	109.3	116.5
Building I and II	100.4	104.4	109.9	112.2	116.0	117.5	113.0	104.4	121.7

Table 4-5 (c) PWL in decibel by Solid surface method.

Machine	1/1 octave band PWL in dB								PWL dB
	63	125	250	500	1000	2000	4000	8000	
Cooling Tower	98.3	101.7	102.8	107.6	109.4	109.4	110.0	108.6	116.5
Building Center	92.9	101.2	103.4	106.6	106.5	102.2	96.1	89.2	111.7
Building Right	85.3	92.1	90.5	99.6	97.0	95.3	89.8	84.1	103.4
Building Left	87.9	95.2	95.1	100.0	98.9	96.9	91.2	85.5	105.0

Table 4-5 (d) PWL in decibel by Linear surface method.

Machine	1/1 octave band PWL in dB								PWL dB
	63	125	250	500	1000	2000	4000	8000	
Cooling Tower N	93.2	101.7	98.9	98.4	100.1	99.8	98.7	95.2	107.2
Cooling Tower S	94.1	91.2	93.7	92.7	91.4	92.2	92.0	89.5	129.0
Cooling Tower W	106.4	109.7	112.6	119.8	122.4	122.5	123.8	122.9	128.6
Cooling Tower E	105.0	107.7	110.7	117.3	119.7	119.8	121.0	120.1	126.0
Building L-NE	88.6	89.2	98.5	99.0	100.7	99.5	94.6	83.8	106.1
Building L-NW	91.4	94.7	99.1	102.9	99.6	93.8	85.0	79.4	106.4
Building L-SW	98.4	97.4	102.1	102.8	106.0	107.9	109.9	107.3	114.8
Building C-NE	96.9	116.3	107.0	106.4	104.8	98.8	89.4	80.33	117.5
Building C-SW	98.8	100.3	101.9	102.1	104.4	105.0	105.3	102.0	112.0
Building R-NE	103.3	105.6	112.3	117.3	117.6	117.5	114.6	105.7	123.5
Building R-SE	91.4	94.7	99.1	102.9	99.6	93.8	85.0	79.4	106.4
Building R-SW	94.4	98.8	100.2	99.3	102.6	107.9	112.4	106.4	115.1

Table 4-5 (e) PWL in decibel by Area surface method.

Machine	1/1 octave band PWL in dB								PWL
	63	125	250	500	1000	2000	4000	8000	dB
Cooling Tower N	92.7	101.2	98.4	97.9	99.6	99.3	98.2	94.7	107.4
Cooling Tower S	93.6	90.7	93.2	92.2	90.9	91.7	91.5	89	100.8
Cooling Tower W	103	109.2	112.2	119.3	121.9	122	123.3	120.5	128.8
Cooling Tower E	106.7	110.1	113.3	121.8	122.4	122.6	123.8	123	129.9
Building L-NE	86.9	87.5	96.8	97.3	99.0	97.8	92.9	82.1	104.4
Building L-NW	86.7	90.0	94.4	98.2	94.9	89.1	80.3	74.7	101.7
Building L-SW	97.6	96.9	101.6	102.3	105.5	107.4	109.4	106.8	114.3
Building C-NE	96.5	115.9	106.6	106.0	104.4	98.4	89.0	79.9	117.1
Building C-SW	104.1	94.7	99.6	98.6	102.2	103.2	105.2	104.7	111.6
Building R-NE	100.2	103.6	107.3	111.4	116.8	118.3	116.4	104.4	122.7
Building R-SE	86.7	90.0	94.4	98.2	94.9	89.1	80.3	74.7	101.7
Building R-SW	101.1	93.9	96.2	99.7	100.1	102.2	103.1	101.4	109.5
Building overall band	107.8	116.1	109.6	109.8	110.5	110.7	111.9	110.1	120.3

Table 4-6 General guidance noise limit at work place.

Description	Noise Limitation
Restricted Work Area	Not exceed 115 dB(A)
Work Area	Not exceed 85 dB(A)
Community Area	Not exceed 65 dB(A)

Source: Shell Internationale Petroleum MIJ.B.V., 1993

Before the construction of new power plant occurred, the acoustical design of the plant is one of the important factor for plant design. It was significant for a capacity design and general maintenance of machines. Engineers try to operate their plant with maximum capacity under excellent safety conditions. They also concerned all conditions under the environmental noise control guidance for human safety at work in the same time. That guideline was three steps of noise design, presented in table 4-6. Mechanical engineers have to measure SPL of every part of machines which were situated inside the operation areas in order to estimate PWL of the plants. When they knew the whole PWL, they will modify the design plan to meet their objectives. The arrangement of machine's position and capacity might use for improving the designs. After that, they get the machine's list to seek the appropriate vendors who can authorize the providing machines under the conditions in that list.

Thus, to facilitate their works, one of engineers developed the Müller's equation (Bies and Hansen, 1988) for the PWL determination of sound source, generally used in the factories. Müller's equation which is used in RPP are explained in Appendix C.2. All of those procedures would occur in the design state of new factory. When the construction completed, the well-known institute will be requested for testing the acoustical design. If their designs were over the limitation in table 4-6, engineer teams will improve the design plan again. Sound pattern and levels of the plant are periodically changed depending on power, operation rate, and their maintenance. Hence, the calculated PWL of the proposed equation in this study would not be equals to calculated PWL of Müller's equation. In this study, the

Müller's equation would be used for the reference PWL of the machines at the initial state to confirm the accuracy of the PWL determination methods.

Decibel addition concept were also used in the selection of PWL of noise sources. Two noise levels that had a different between each other more than 10 dB will commonly be considered only the larger levels. This criteria will be considered during the comparison of two noise levels from different sources.

Ray-tracing technique or Grid-system method was introduced to explain the sound pattern distribution of noise sources of RPP. In outdoor environment SPL measurement were measured using 25x25, 50x50, and 100x100 grid-size, while indoor environment SPL were measured using 5x5 and 10x10 grid-size for plotting the equivalent line (contour line) around the operation area. The X-Y coordinate was used to identify the position of the measurement. Contour line was drawn by kringing equation of surfer mapping surface software version 5.01 for windows. (Golden Software, 1993) The author suggested this technique was very useful for identification of sound sources location and its directivity in the industrial areas.

This study concerned only large source during the prediction processes. PWL of the cooling tower and main building were selected noise sources for emission part of prediction model. Those sources can be determined using the appropriate methods from the proposed methods of this study. A large number of sources would cause the complicated input data. That will bring the errors to predicted values that is caused by the mistaken input.

Noise sources inside the building were almost located in the central part of the building with different elevated plane. The central part had 4 floors; 0, 5, 10, and 15 meters height. This part contained all of equipment of steam turbine generation system. Left wing and right wing contained all equipment of gas turbine generation system except exhausted duct, air inlet cleanser, and HRSG. These parts had only ground floor because the air inlet system were installed from 10 meter height to the ceiling. These parts also contained ventilation fans and air-conditioned units for control room. Each part of the building looks like a separated large industrial hall.

The distribution contour map inside the building also presented the different levels of each part. There were a lot of uncertainty data input such as absorption coefficient and transmission loss of enclosure material for calculating noise source using indoor conditions of ISO 3746. (ISO, 1979) The outdoor measurement with ordinary SLM was the best conditions for estimating PWL in this study. The author try to find the profitable methods to predict PWL of main sources. She decided to divide the main building into three parts; left, right and central part for noise source determination.

SPL measured around noise source in outdoor environment presented the significant sources to be considered using decibel addition criteria, grid-system criteria, and Müller's equation. In table 4-5 (a) to (e) presented the PWL predicted from those proposed equations. Cooling towers were calculated using the methods of point source, Colenbrander, Solid surface, linear surface, and area surface. The main buildings were also calculated using the methods of Colenbrander, Solid surface, linear surface, and area surface. Small sources in table 4-5 (a) were insignificant sources under both criteria; decibel addition and grid-system. PWL of motors, pumps, cooling fin fans had lower than PWL of large sources exceeding 10 dB. The contour line also showed the main sources at cooling tower and main building in figure 4-7.

Table 4-7 Selected noise source for testing predicted immission noise levels.

Name	Eq.	1/1octave band PWL, dB								PWL
		63	125	250	500	1000	2000	4000	8000	dB
Cooling Tower	Colen	67.8	81.5	91.4	103.8	109.4	110.9	111.5	108.3	116.5
Building Left-F	Area	86.9	87.5	96.8	97.3	99.0	97.8	92.9	82.1	104.4
Building Right-F	Area	100.2	103.6	107.3	111.4	116.8	118.3	116.4	104.4	122.7
Building Center-F	Area	96.5	115.9	106.6	106.0	104.4	98.4	89.0	79.9	117.1
Building Left-B	Area	97.6	96.9	101.6	102.3	105.5	107.4	109.4	106.8	114.3
Building Right-B	Area	101.1	93.9	96.2	99.7	100.1	102.2	103.1	101.4	109.5
Building Center-B	Area	104.1	94.7	99.6	98.6	102.2	103.2	105.2	104.7	111.6

Colenbrander and Solid surface methods calculated all band levels of cooling tower equal to 116.5 dB. While the others methods were over or under that levels. The reference levels of cooling tower, calculated by Müller's equation was about 115.9 dB. Yamamoto, Takagi, and Hiramatsu (1990) recommended the solid surface methods ordinarily used for determining PWL of cooling tower in Japan. However, the Colenbrander's methods was easier way to measure and calculate PWL of sources. The author decided to take the PWL of cooling tower from Colenbrander's methods inputting to the prediction model.

Main buildings were directly emitted the sound energy of complexity of multi-source inside the enclosure wall through environment. Every square meter of the wall can radiated sound energy according to the sound energy inside the building. Short distance applied to PWL determination making the point source concept was not enough to be considered. The distance between source to immission point was the key parameter to choose the determination equation. In this study, the area surface method was potentially to be a PWL determination methods of the buildings.

The selected PWL determination methods were possibly appropriate way to predict RPP's noise source influent by their arrangement of source positions. Stüber 's method is the one of the PWL determination by point source concept for PWL determination of industrial large or multi-sources. It recommended for PWL determination of large sources without enclosure wall. It was not applied this method in this study because of the enclosure building and practice of on-site measurement at advised height. The selected noise sources for the emission part of the prediction model were presented in table 4-7. There were 16 numbers of sources in RPP's operation areas.

4.3 Sensitivity Analysis

According to equation 2.36, input part of power plant prediction model needs 2 key's terms; emission part and transmission part. PWL of the outstanding machines and the transfer functions which were explained in 2.5.2.1 and 2.5.2.3 were considered. Each function was dissimilar influences to the predicted SPL at the immission point.

Noise source determination was an initiate function of the model. Momentarily, we have no PWL database of machines, ordinarily used in factories in Thailand. Although, we can use PWL of machines from the vendor's list for new power plant but we also do not have the PWL of the old machines in case of the expansion and re-evaluate the plants. In order to provide the PWL of plant, the on-site SPL measurement and intensity measurement were practically used. However intensity measurement needs specific equipment and expensive cost more than SPL measurement. Thus, SPL measurement with the ordinary SLM would be popular method for PWL determination for long time in the future in Thailand.

The transfer functions were another important parameter to be considered in the prediction model. Each transmission path was concluded from sound properties in an environment. Sound wave has three properties that affected sound propagation outdoor; reflection, absorption and diffraction. When sound waves attach to a plane surface, part of energy can reflect, transmit and absorb. Sound energy that was indirectly come from two or more times reflections, however small, was absorbed.

In case for acoustic reflecting obstacle, the low absorption and transmission material, acoustically hard plane, can be considered to reflect the sound energy as the mirror image source. If the sound waves attach to a curved surfaces or corner, the sound ray will be focused on concave surfaces, dispersed on the convex surfaces and twice reflections from both perpendicular surfaces. The reflections on the lateral side will cause the standing wave and flutter echo. Some small energy of sound wave that is meet the surfaces; is lost by the effective roughness, porosity, flexibility and resonant properties of structure material that can be called as absorption properties. The efficiency of absorbing material is represent by "0" as no absorption and "1" as perfect absorption, depending on frequency of sound.

The last part of energy that encounters the obstacle passes round surfaces as if it did not exist, forming very little shadow. If the sound is high frequency and short wavelength, each point on a wave front can be considered as a new sound source called Huygen's principle sufficiently. If the wall is applied to obstruct the wave front, it can be considered as a secondary wavelets radiating away from wall in all directions. The secondary wavelets combine with wavefront to form new wave front within spread out cylindrical in the quadrant behind the wall, called as the shadow region. If the secondary wavelets become the opening surface, it will radiating the lowest intensity hemispherical sound into space beyond the wall. From these reason, behind the barrier away become the shadow zone, relies on the size of barrier or opening of structure.

Thus, those three properties affect transmission path data between emission and immission point in outdoor environments. Sound attenuation or reflection of each transfer function in each propagation path can explain in terms of sound reflection, sound absorption, sound diffraction and sound transmission. In each transfer function terms would be used several concept of sound attenuation to conclude the equation. Some cases would finally cause amplification or attenuation as presented by plus or minus sign respectively in transfer function.

There were five functions illustrating sound propagation in each transmission path. All of the correction attenuation that is used in prediction model is explained in 2.5.2.3. Divergence attenuation is the reduction of sound energy by inverse square law, decreasing double energy by double distances. It was the most important terms for sound propagation in outdoor environment. Figure 4-12 showed the scatter plot of divergence attenuation with variety of distance (R). It is found that the divergence attenuation possibly sensitive only in the range of short distances (1-400 meters). Because there were slightly decibel changed or nearly steady level in range of long distance. (more than 400) Thus, the determination of the divergence attenuation used the altered equation under "R" conditions as shown in equation 2.46 and 2.47.

Air absorption attenuation is the reduction of sound energy by air absorption especially in case of large distance. Temperature and velocity of medium can alter the direction of the sound wave while the viscosity causes absorption. Sound absorption properties of air medium relies on medium temperature and relative humidity. When temperature and relative humidity increase the absorption, caused by atmospheric viscosity also increases. When the perpendicular distance, R, orderly changed, the air absorption attenuation would be raised up at the same temperature and relative humidity. This terms will affect with less magnitude attenuation in comparing with divergence attenuation in the range of short distance as shown in figure 4-13. The equation which determined air absorption was shown in equation 2.48. This attenuation was not significant parameter in short distance prediction (not more than 200 meters) except in high frequency.

Ground effect can be both sound attenuation and sound reflection as shown in minus and plus mathematical operand. The porosity of ground was important parameter to identify its attenuation or reflection. Sound energy will reflect on the hard plane more than other properties and also absorb on the soft plane because of ground density or porosity. G-type (Ground factor) is the key parameter to identify the correction type of ground effect. In case of RPP's ground properties, there were not exceed ± 1 dB in every paths.

When reflecting obstacle occurred in any transmission path, the specification of obstacle in table 2-13 would be fulfilled. The incident angle was equal to the reflecting angle in figure 2-7. We should be concerned the incident path and reflecting path environment because these environment would be caused the different levels of reflection. If both environment were unlike the mirror source with new transmission path adding to the prediction. Reflecting levels of this case were depended on the PWL of new source could not be concerned by this study. From reflecting obstacle effect, it was not more +3 decibels correction for every type of obstacle surfaces.

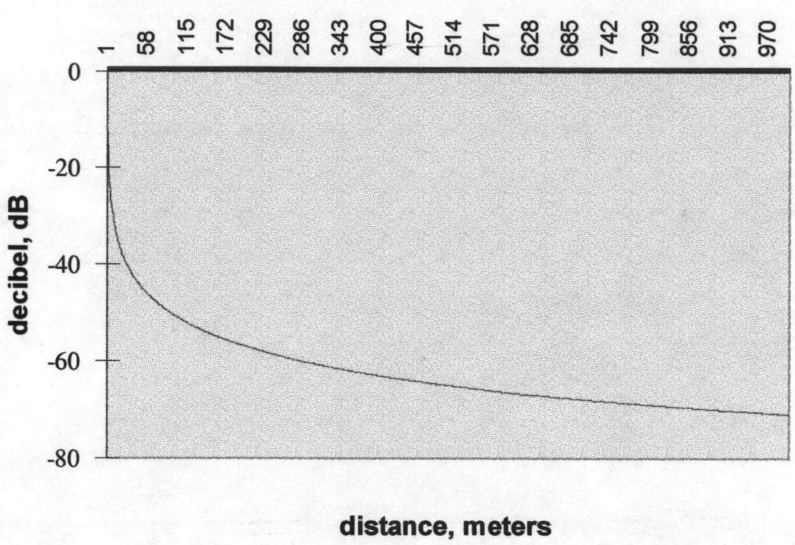


Figure 4-12 Divergence attenuation level by varying "R" distance.

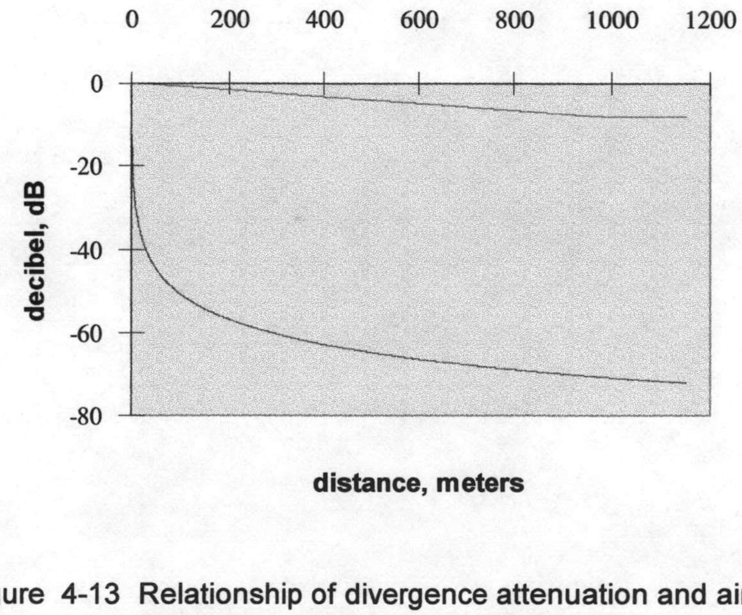


Figure 4-13 Relationship of divergence attenuation and air abssorption attenuation with the same "R" distance.

This case will omit the mirror source in account of some reflection once or twice times from the obstacle. Reflection was frequency independent and reflecting angle was not more than 85 degrees. Reflecting obstacle caused the reflection for the transmission path, always displayed plus operand in the transfer function.

When screening obstacle or barrier was occurred in any transmission path, the diffraction attenuation would mainly be considered in case of noise barrier. The screening obstacle function can calculate sound diffraction caused by barrier from three edges; vertical edge, left edge and right edge as shown in table 2-15. The reflection of sound between barrier and ground surface be also concerned. For RPP case, some noise source building or structure represent sound diffraction at the edge of them. Diffraction attenuation by screening obstacle was about 20 dB.

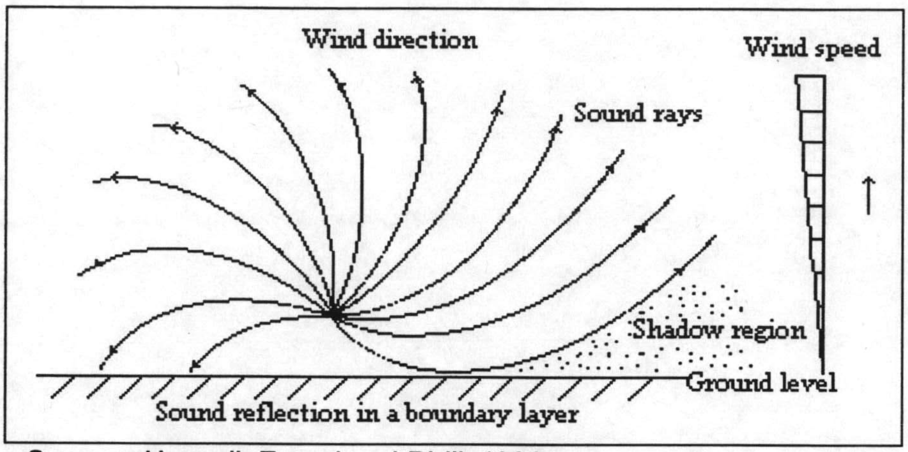
Transfer functions affect attenuation level in many kind of environmental condition with the different magnitude. The author suggested that important function should be concerned or ignored by given ranking marks in the table 4-8 while the operator used the prediction model at any immission point in the vicinity of noise source. The minimum marks was the most meaningful function would be concerned. There are the other transfer functions that were not mentioned in this study such as wind condition with temperature gradient, source directivity, vegetation attenuation and so on.

Table 4-8 Ranking criteria for transfer function

Name of Transfer Function	Ranking marks	Type
Divergence attenuation	1	Standard
Screening obstacle attenuation	2	Option
Ground effects	3	Standard
Reflecting obstacle attenuation	4	Option
Air absorption attenuation	5	Standard
Others; Vegetation obstacle, Internal scattering obstacle, etc.	6	None

Although, the measurement conditions of this study were concerned the standard practice in wind conditions (figure 4-14) as specified as follow;

- Wind direction within an angle of 45 degrees of the direction connecting the center of the sound source and the center of the specified area, with the wind blowing from the source to receiver.
- Wind velocity approximately between 1 and 5 m/s (3 and 15 ft/s), measured at a height of 3 to 11 meters (10 to 36 ft) above the ground.
- Propagation (in any near horizontal direction) under a well developed ground based temperature inversion depending on ISO 9613. (ISO, 1993)



Source : Hassall, Zaveri and Phill, 1988

Figure 4-14 Wind conditions influent sound wave

The influent caused by wind and temperature gradient might occurred in the prediction verification. From the observation, the author found that RPP's operation area were the upwind condition in southwestern part. There were 34 immission points located in that part. They had about 150 meter in horizontal distance far from main buildings. They absolutely located under the shadow region of upwind condition. (Hassall, Zaveri and Phill, 1988) Generally, the magnitude of wind correction is very difficult to calculate. It was insensitive to minor change of wind conditions except the shadow region under upwind zone. It can found that region had more 20 dB lower than usually conditions.

The author observed the distribution pattern of RPP's cooling towers in contour map and their location positions. Cooling towers had their own unique pattern of sound emitted along with water splashing side higher than the other side. The directivity correction terms, caused by the arrangement of sound sources would be concerned by conclusion of Deutsche's study. (VDI, 1985) This directivity characteristic was very difficult parameter to be concluded during the measurement, however, the intensity magnitude plot can take directivity of source. This study decided to use the explanation in figure 4-15 for determining the directivity correction of RPP's cooling tower.

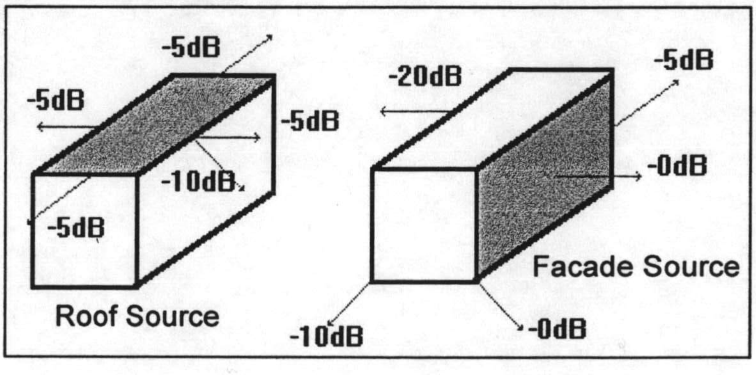


Figure 4-15 Noise source directivity correction.

4.4 Predicted Sound Pressure Level from the Prediction Model

All of SPL predicted from power plant noise prediction model are in Appendix D. The scatter plot in figure 4-16 to 4-19 showed the comparison between measured SPL and predicted SPL by adding case by case of transfer function corrections.

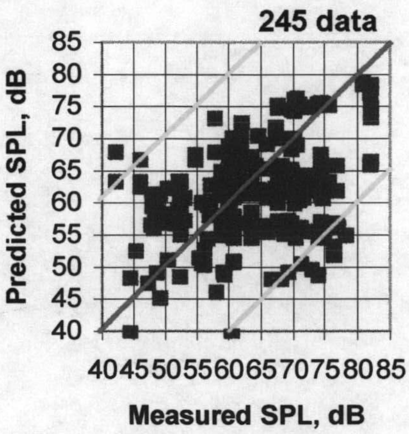


Figure 4-16 The comparison between measured SPL and predicted SPL with divergence attenuation.

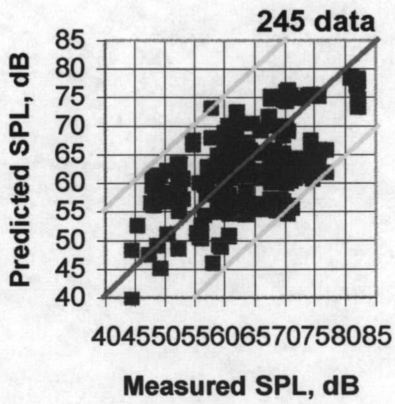


Figure 4-17 The comparison between measured SPL and predicted SPL with divergence attenuation, air absorption attenuation, and ground effect corrections.

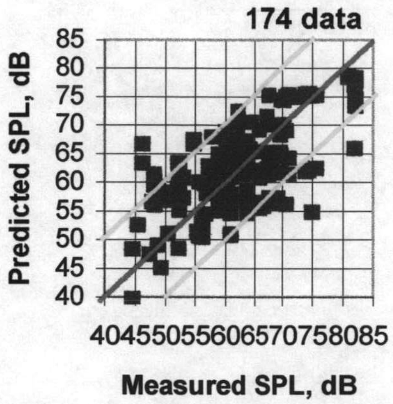


Figure 4-18 The comparison between measured SPL and predicted SPL with divergence attenuation, air absorption attenuation, ground effect corrections excluding the adjacent position of small sources.

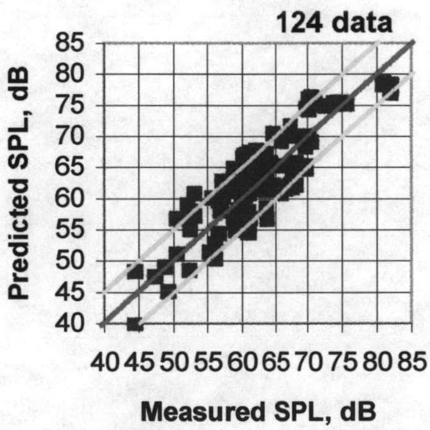


Figure 4-19 The comparison between measured SPL and predicted SPL with divergence attenuation, air absorption attenuation, ground effect corrections excluding the adjacent position of small sources and the upwind conditions.

From figure 4-16 to 4-19, the ideal equivalent line (red line) is the measured SPL equal the predicted SPL. The lateral lines (yellow line) which is adjacent to the ideal line was the interesting region to conclude the accuracy levels of the prediction model in case of RPP. The 16 noise sources and 115 immission points were used for testing the accuracy of power plant noise prediction model. The 245 transmission paths were used for considering during the prediction. First plot (figure 4-16) showed ± 20 dB interesting region caused by the predicted values with the divergence attenuation. The second plot (figure 4-17) showed ± 15 dB region of the variable values made by the combination of divergence attenuation, air absorption, ground effect corrections. The major corrections of this prediction were divergence while the air absorption and ground effect corrections increasingly caused the attenuation about 1 to 3 dB particularly in long distance. All of measurement data, 245 samples completely plotted in both scatter graph.

Some data exceeded ±10 dB region (interesting zone). After re-checking those immission positions, the author found three outstanding conditions affected to the predicted values. Source directivity of cooling towers, insignificant sources adjacent to the immission point, and the shadow zone in upwind conditions were found during this analysis. The predicted values, located close to the insignificant sources were lower than the measured values because of the influent of near field sound energy.

The author try to explain the accuracy of this prediction model by adding directivity corrections to the predicted values and excluding the insignificant sources out of this analysis at the same time. The results of those operation were shown in figure 4-18 with the accuracy range about ±10 dB. The number of samples were reduced from 100% to 71.0% by this elimination.

There were 34 immission points, located at 150 meters range from the edge of the main buildings. All of measurement positions had the predicted values larger than the measured values. It might caused by the shadow zone of the upwind region. (Southwestern) In this region, the measured SPL read from SLM might be lower than the actual values as high as 20 to 30 dB (Hassall, Zaveri, and Phill, 1988) Karsten (1985) researched the sound outdoor propagation under the influence of wind and temperature gradients. He found that sound energy were decreased about 5 to 20 dB at least in distance upto about 100 to 150 meters in horizontal plane with 2 to 2.5 m/s wind speed at 10 meters height. Michael, David, and Gilles (1995) researched the attenuation in shadow zone by air turbulence in the range of 700 meters long. He found that sound levels in the shadow region in first 100 meters rapidly dropped in the range of -20 to -25 dB with 5 m/s wind speed at 10 meters.

However, in this study was not including these corrections. Trying to explain the accuracy of this prediction model, the author decided to eliminate all of those upwind positions out of the analysis. The scatter plot in figure 4-19 presented the accuracy of the prediction model were in the ranges of ± 5 dB with 50.6% of all samples. Those corrections that is added or excluded from the power plant noise prediction model in order to explain the accuracy of the prediction model, were classified in table 4-9.

This power plant noise prediction model had 10 dB accuracy range according to model assumption and consideration methods of input part under downwind conditions. The comparison of predicted SPL and measured SPL of the last scatter plot were presented by contour map methods in figure 4-20 (a) to (c).

Table 4-9 Selected Transfer Functions for the Correction of Prediction Model.

Accuracy Levels			
± 20 dB	± 15 dB	± 10 dB	± 5 dB
Divergence, Small source, Upwind Position	Divergence, Small source, Upwind Position	Divergence, Upwind Position	Divergence
	Air absorption, Ground effect	Air absorption, Ground effect	Air absorption, Ground effect
		Directivity	Directivity

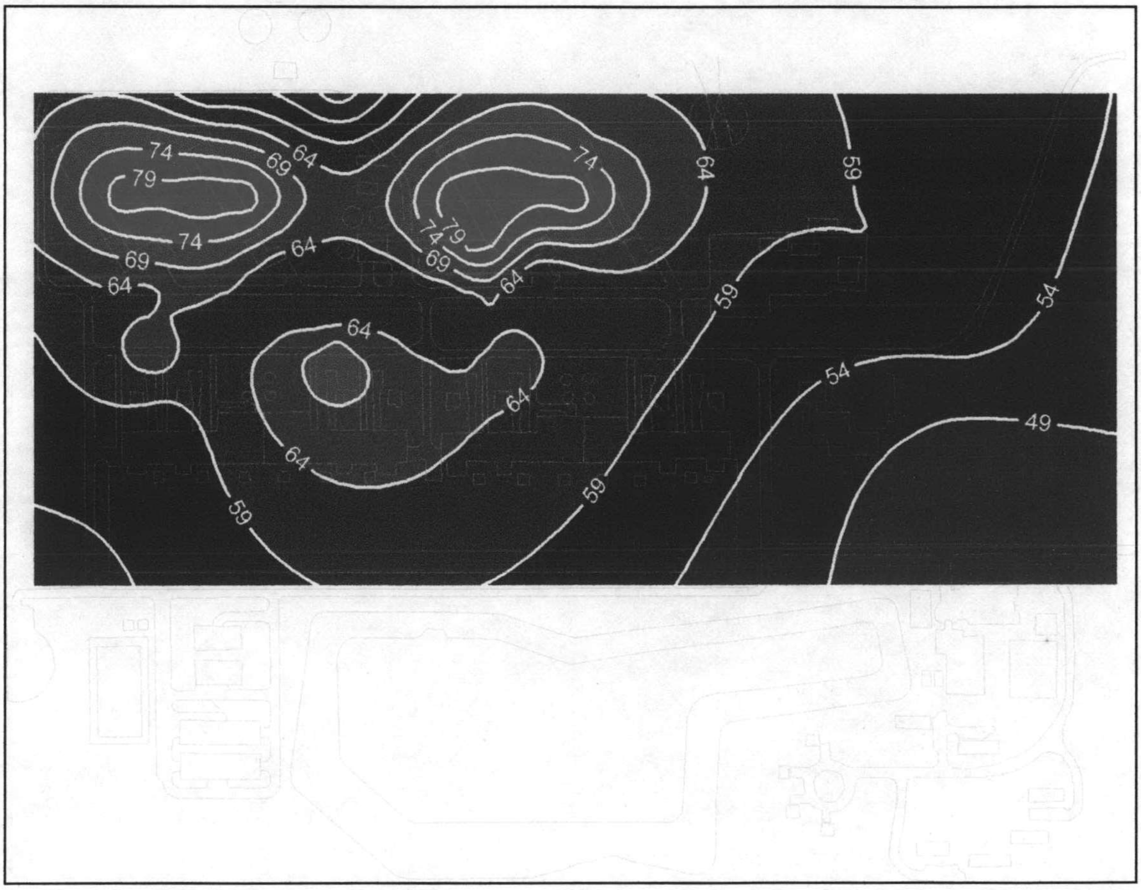


Figure 4-20 (a) The contour map of selected SPL measured at immission point .

Figure 4-20 (b) The contour map pf predicted SPL of considered immission point

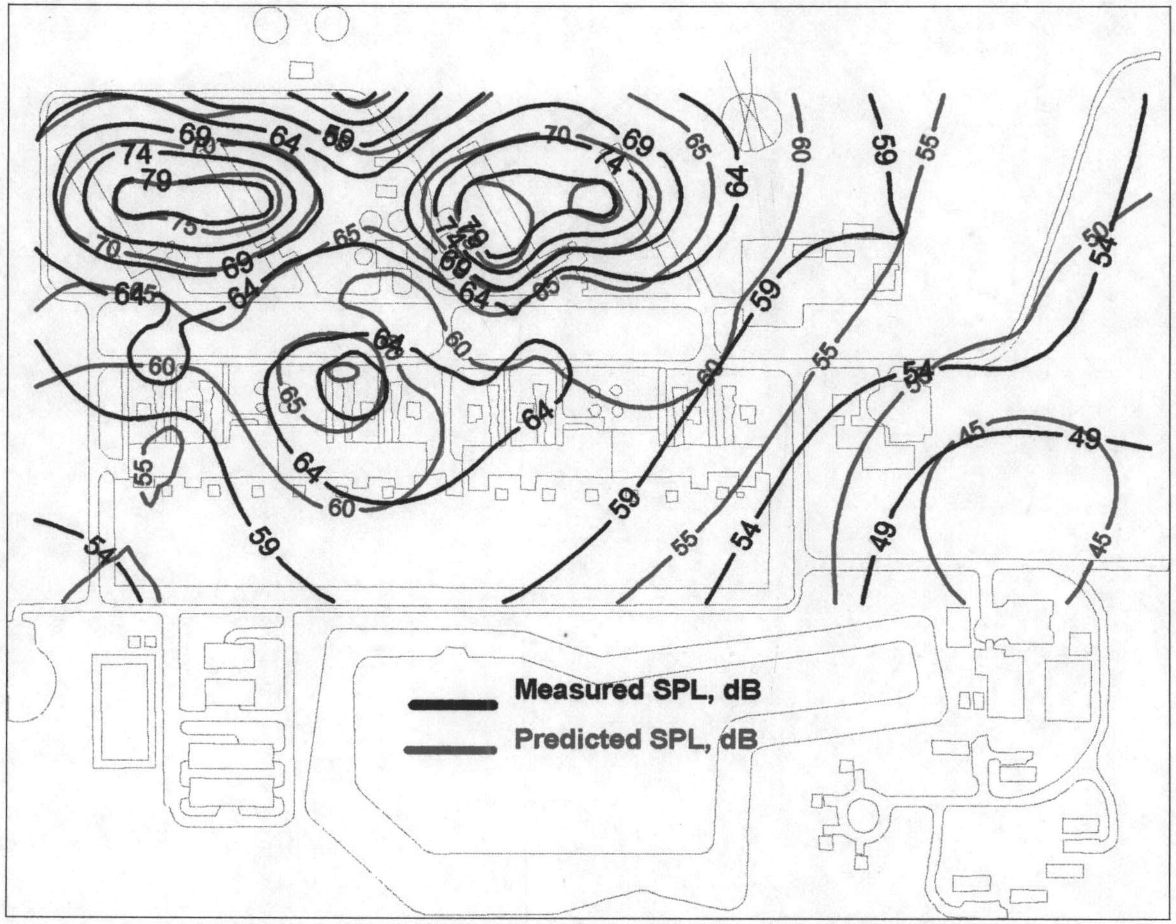


Figure 4-20 (c) Overlay map of measured SPL and predicted SPL with the same conditions