Acoustical Analysis

There are many different acoustical issues that could be studied and dealt with in a hotel similar to the BWI Hilton. But the new mechanical design work previously described in the "Mechanical Systems Design" section provided several specific areas to be studied. These include the acoustics related to the new chillers, cooling towers, and fan coil units. Each topic is described next, and the corresponding calculations are also included. Please refer to Appendix K – Acoustical Analysis for additional information.

Chiller Acoustical Analysis

The most significant difference between the original mechanical system and the new design involves the new chiller units placed in the main mechanical equipment room. The location of the chillers is not a problem since they are on the parking level. However, the restaurant of the BWI Hilton is located directly above the mechanical room. So the acoustics of the chiller and how it affects the restaurant are described next.

The mechanical equipment room surface areas are shown below in Table 39 – Mechanical Room Surfaces. Sound absorption coefficients were assumed for the given surface materials from provided data given by M. David Egan. Typical values for pump sound pressure levels were assumed from data given by Egan. The values used for the chillers in the room were provided for the York MaxE centrifugal chillers operating at full load (part loads typically have different sound pressure levels).

For these calculations, it was assumed that the size of the mechanical room did not get any larger. The surface areas are given next in Table 39 – Mechanical Room Surfaces.

Table 39 - Mechanical Room Surfaces

Surface	Area (sf)
Floor	1206.0
Ceiling	1206.0
Exterior Walls	1483.6
Interior Walls	1350.3
Total	**5245.9**

Typical Room Criteria (RC) levels are defined below in Table 40 – Restaurant RC Levels.

Table 40 – Restaurant RC Levels

Space	RC Level Range	RC Level Used
Restaurant	35-40	35

All the calculations were modeled after those provided by Egan for transmission loss (TL) design. The following equations were used for these calculations.

Sound absorption:

$a_2=\Sigma(S*\alpha)$

Total sound pressure level (dB):

$L_{p,tot}=10*\log(10^\wedge(L_1/10)+10^\wedge(L_2/10))$

Transmission Loss (dB):

$TL=NR-10*\log(a_2/S)$

Noise Reduction (dB):

NR=L1-L2 *(source minus receiver)*

Mass Law:

$TL=10*\log(1/\tau)=20*\log(\omega*m/(2*\rho_0*c))$

The sound absorption coefficients and the absorption values (sabins) were calculated first for the surface materials in the mechanical room (source room). Only the exposed insulation material was used for the ceiling, and the 12 in concrete slab was not used for the absorption calculations. These calculations are shown below in Table 41 – Mechanical Room Absorption.

Table 41 - Mechanical Room Absorption

Surface Material	Surface Area (sf)	Sound Absorption Coefficient					
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
12 in Concrete Walls	1483.6	0.01	0.02	0.04	0.06	0.08	0.10
8 in CMU Block Walls	1350.3	0.10	0.05	0.06	0.07	0.09	0.08
Concrete Floor	1206.0	0.01	0.02	0.04	0.06	0.08	0.10
2 in Rigid Insulation Ceiling	1206.0	0.38	0.60	0.78	0.80	0.78	0.70

Surface Material	Surface Area (sf)	Sound Absorption Coefficient					
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
12 in Concrete Walls	1483.6	14.84	29.67	59.35	89.02	118.69	148.36
8 in CMU Block Walls	1350.3	135.03	67.51	81.02	94.52	121.52	108.02
Concrete Floor	1206.0	12.06	24.12	48.24	72.36	96.48	120.60
2 in Rigid Insulation Ceiling	1206.0	458.28	723.60	940.68	964.80	940.68	844.20
$a_2 = \Sigma S\alpha$ (sabins)	-	620.20	844.91	1129.28	1220.70	1277.37	1221.18

The second step was to determine the sound pressure levels in the mechanical room that were emitted by the mechanical equipment. Table 42 –

Sound Pressure Levels defines all the values used for the equipment. The sound data listed for the chillers is actual sound levels provided for the York MaxE centrifugal chillers. Since the actual sound levels of the pumps and boilers were not know, the sound levels used were assumed based on typical values given by Egan.

Table 42 - Sound Pressure Levels

(2) York MaxE Chillers	Sound Pressure Level (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
(1) Centrifugal Chiller	70	72	74	74	78	79
(2) Centrifugal Chillers	73	75	77	77	81	82
Original Mech Room	**Sound Pressure Level (dB)**					
	125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
(1) Pump	80	82	87	86	80	77
(6) Pumps	88	90	95	94	88	85
(1) Boiler	92	89	86	83	80	77
(3) Boilers	95	92	89	86	83	80
Total	**96**	**94**	**96**	**94**	**89**	**86**
New Mech Room	**Sound Pressure Level (dB)**					
	125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
(1) Centrifugal Chiller	70	72	74	74	78	79
(2) Centrifugal Chillers	73	75	77	77	81	82
(1) Pump	80	82	87	86	80	77
(6) Pumps	88	90	95	94	88	85
(1) Boiler	92	89	86	83	80	77
(3) Boilers	95	92	89	86	83	80
Total	**96**	**94**	**96**	**95**	**90**	**87**

The third step is to calculate the transmission loss required by the ceiling that separates the mechanical room from the restaurant. Egan only provides values for a 6 in concrete slab ceiling, but the BWI Hilton has a 12 in concrete slab. Therefore, the mass law was used to determine approximate values for the thicker slab. The mass law for transmission loss is simply a 6 dB increase in TL with the doubling of mass of the material. The 12 in slab would have twice as much mass as the 6 in slab, so 6 dB are added at each octave band to the given 6 in concrete slab values. The mass law affects on the sound pressure levels are shown below in Table 43 – Mass Law.

Table 9 - Mass Law

Material	Sound Pressure Level (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
6 in concrete slab ceiling	38	43	52	59	67	72
Mass Law: +6 dB	6	6	6	6	6	6
12 in concrete slab ceiling	44	49	58	65	73	78

The required transmission loss values for the ceiling construction are shown below in Table 44 – Transmission Loss Calculations.

Table 44 - Transmission Loss Calculations

Chiller Noise Only	Sound Pressure Level (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Chiller Noise	73	75	77	77	81	82
RC-30 Background Noise	45	40	35	30	25	20
Required NR (dB)	28	35	42	47	56	62
10*log(a_2/S)	-3	-2	0	0	0	0
Required TL (dB)	25	33	42	47	56	62
12 in Concrete Slab Ceiling	44	49	58	65	73	78
Original Mech System Design	**Sound Pressure Level (dB)**					
	125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Mech Room Noise	96	94	96	94	89	86
RC-30 Background Noise	45	40	35	30	25	20
Required NR (dB)	51	54	61	64	64	66
10*log(a_2/S)	-3	-2	0	0	0	0
Required TL (dB)	48	53	61	65	64	66
12 in Concrete Slab Ceiling	44	49	58	65	73	78
New Mech System Design	**Sound Pressure Level (dB)**					
	125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Mech Room Noise	96	94	96	95	90	87
RC-30 Background Noise	45	40	35	30	25	20
Required NR (dB)	51	54	61	65	65	67
10*log(a_2/S)	-3	-2	0	0	0	0
Required TL (dB)	48	53	61	65	65	68
12 in Concrete Slab Ceiling	44	49	58	65	73	78

To determine if the given ceiling construction is sufficient to meet the RC-30 criteria, the TL values given for the 12 in concrete slab ceiling should be higher than the required TL values listed for each design case. The 12 in slab easily exceeds the requirements for the chillers only. The TL values for the 12 in slab in the original and new mechanical systems designs are not sufficient to meet the required TL values. However, this TL of the 12 in slab only takes into account the transmission loss through the slab itself. It does not consider the 2 in of rigid insulation under the slab or the flooring materials used for the restaurant floor. Therefore, it can be assumed that the 12 in slab with the 2 in rigid insulation and restaurant floor materials will be sufficient to reduce the mechanical equipment sound levels into the restaurant.

Fan Coil Unit Acoustical Analysis

It is known that the fan coil units in all the guest rooms will emit certain sound power levels. It is important to know if these sound levels are at appropriate levels for typical guest rooms. To analyze the acoustics of the fan coil units in the guest rooms, the maximum sound power levels will be computed for the desired guest room RC level.

For these calculations, a typical guest room size was assumed to be nearly consistent for all 279 guest rooms in the BWI Hilton. Any minor changes to the size and shape of the guest rooms was assumed to be negligible. The surface areas are given next in Table 45 – Guest Room Surfaces.

Table 45 – Guest Room Surfaces

Surface	Area (sf)
Floor	282.0
Ceiling	282.0
Exterior Walls	108.3
Interior Walls	541.5
Total	**1213.7**

Typical Room Criteria (RC) levels are defined below in Table 46 – Guest Room RC Levels.

Table 46 – Guest Room RC Levels

Space	RC Level Range	RC Level Used
Guest Room	25-35	30

The following equations, as outlined by Professor Courtney Burroughs, were used for these calculations.

Sound power level (dB):

$$L_W=L_p+10*\log(R_T)-6$$

Room constant:

$$R_T=a_2/(1-\alpha_{SAB})$$

Sound absorption:

$$a_2=\Sigma(S*\alpha)$$

Sabine absorption:

$$\alpha_{SAB}=\Sigma(S*\alpha)/\Sigma S$$

The maximum sound power levels will be compared to the given sound power levels of the two selected fan coil units to be used in the guest rooms of the BWI Hilton project. The sound data provided from Carrier is shown below in Table 47 – FCU Sound Power Levels.

Table 47 - FCU Sound Power Levels

Carrier 42S Fan Coil Unit	Sound Power Level (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
FCU-1: 42SGA03	65	57	53	49	41	39
FCU-2: 42SGA04	69	60	56	51	42	40

The sound absorption coefficients and the absorption values (sabins) were calculated first for the surface materials in a typical guest room. These calculations are shown below in Table 48 – Guest Room Absorption.

Table 48 - Guest Room Absorption

Surface Material	Surface Area (sf)	Sound Absorption Coefficient					
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
12 in Precast Concrete Wall	108.3	0.10	0.05	0.06	0.07	0.09	0.08
5/8 in GWB w/ Insulation	541.5	0.55	0.14	0.08	0.04	0.12	0.11
Carpet on Concrete Floor	282.0	0.02	0.06	0.14	0.37	0.60	0.65
Painted 1/2 in GWB Ceiling	282.0	0.29	0.10	0.05	0.04	0.07	0.09

Surface Material	Surface Area (sf)	Sound Absorption Coefficient					
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
12 in Precast Concrete Wall	108.3	10.83	5.41	6.50	7.58	9.75	8.66
5/8 in GWB w/ Insulation	541.5	297.80	75.80	43.32	21.66	64.97	59.56
Carpet on Concrete Floor	282.0	5.64	16.92	39.48	104.34	169.20	183.30
Concrete Ceiling	282.0	81.78	28.20	14.10	11.28	19.74	25.38
$a_2 = \Sigma S\alpha$ (sabins)	-	396.05	126.34	103.39	144.86	263.66	276.90

The next step is to calculate the maximum sound power levels in a typical guest room based on an assumed level of RC-30. The values used in the equations listed from above are given below in Table 49 – Sound Power Level Calculation.

Table 49 - Sound Power Level Calculation

Typical Guest Room	Octave Band Center Frequency					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
RC-30 Sound Pressure Level (dB)	45	40	35	30	25	20
Sabine Absorption (α_{SAB})	0.33	0.10	0.09	0.12	0.22	0.23
Room Constant (R_T)	587.87	141.02	113.02	164.49	336.83	358.75
Max Sound Power Level (dB)	67	55	50	46	44	40

The final step is to compare the maximum sound power levels with the actual fan coil unit sound power levels. Please see Table 50 – FCU Compliance at RC-30 for the comparison between the FCUs and the maximum values.

Table 50 - FCU Compliance at RC-30

Typical Guest Room	Sound Power Level (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Max Sound Power Level	67	55	50	46	44	40
FCU-1: 42SGA03	65	57	53	49	41	39
FCU-1 Compliance?	Yes	No	No	No	Yes	Yes
FCU-2: 42SGA04	69	60	56	51	42	40
FCU-2 Compliance?	No	No	No	No	Yes	Yes

It can be seen from the data below that both FCU-1 and FCU-2 only comply with the RC-30 levels at 125 Hz, 2000 Hz, and 4000 Hz. Therefore, something must be changed. Either the sound power levels of the fan coil units, the materials and absorption in the guest room, or the maximum allowable sound pressure levels must change.

Table 51 - Adjusted Sound Power Level Calculation

Typical Guest Room	Octave Band Center Frequency					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
RC-35 Sound Pressure Level (dB)	50	45	40	35	30	25
Sabine Absorption (αSAB)	0.33	0.10	0.09	0.12	0.22	0.23
Room Constant (RT)	587.87	141.02	113.02	164.49	336.83	358.75
Max Sound Power Level (dB)	72	60	55	51	49	45

If the RC-30 level is strictly set, then either the fan coil units will need to be changed or adjusted or the guest room surface materials will have to change. If not, the easiest way to get compliance is to adjust the RC level rating that is acceptable for the guest rooms. The adjusted sound power levels and adjusted compliance of the FCUs can be seen above in Table 51 and below in Table 52, respectively.

Table 52 - Adjusted FCU Compliance at RC-35

Typical Guest Room	Sound Power Level (dB)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Max Sound Power Level	72	60	55	51	49	45
FCU-1: 42SGA03	65	57	53	49	41	39
FCU-1 Compliance?	Yes	Yes	Yes	Yes	Yes	Yes
FCU-2: 42SGA04	69	60	56	51	42	40
FCU-2 Compliance?	Yes	Yes	No	Yes	Yes	Yes

As can be seen above in Table 52 – Adjusted FCU Compliance at RC-35, the fan coil units comply at all the center octave band frequencies for both FCU-1 and FCU-2. The RC-35 is the upper limit of the acceptable range of RC levels for hotel guest rooms, as listed in Table 34 of Chapter 47 – Sound and Vibration Control in the 2003 ASHRAE Applications Handbook.

Cooling Tower Acoustical Analysis

The original mechanical system design required the use of a two-cell induced draft cooling tower that was located on the ground outside of the BWI Hilton. The new mechanical system design also uses a very similar model cooling tower, and the location remained the same, as well. However, the noise levels of the cooling tower are compared to determine if there will be any community objection to their location.

A big benefit to the new cooling towers used on the Hilton Hotel at BWI Airport project is that the new cooling towers have a smaller capacity than the original cooling towers. This reduced load may have some affect on fan size and fan speed, which could affect the overall sound levels emitted by the cooling towers.

When researching the cooling tower acoustical analysis procedure, the method of calculating the outdoor noise levels is typically done with Composite Noise Rating (CNR) curves. These curves are then “corrected” and the corresponding predicted community reaction levels are determined. A comparison could be done between one of the standard cooling towers (with 1800 rpm fan motor speeds) and one at lower noise levels (with 1200 rpm fan motor speeds).

However, a Marley cooling tower sales representative said that the 1200 rpm cooling towers are only quieter than the 1800 rpm cooling towers by about 4 dBA total. Since this difference is not that significant and the community reaction levels can only be predicted, the entire CNR procedure was not done for this thesis project.

It can be expected that the community reactions to the lower dBA levels of the 1200 rpm cooling towers will be more favorable (or at least less negative) than that of the 1800 rpm cooling towers. Even though community reaction of the cooling towers affects the image of the BWI Hilton, it is only a small portion of the design decisions used in selecting the equipment to be used on the project. Since the BWI Hilton is located in a commercial area with many other hotels and away from any individual residences, it is not expected that there will be much of a reaction from the community.

Acoustics Conclusions

Of the many important issues dealing with the acoustics related to the mechanical systems, the chillers, fan coil units, and cooling towers were all analyzed. Separate conclusions for each type of equipment and application are described previously within each of the analyses.