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Low Cost Redesign of Coil Assemblies for Ergonomic Improvements

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ABSTRACT

This paper investigated into an alternative approach to solving cooling problems in two typical shopping complexes in Malaysia. For each case, an investigation was initially conducted to capture a general idea of poor indoor cooling suffered by the business operators and patrons. Ergonomics methods such as unstructured interviews and direct observations (DOs) were applied to obtain information on the major complaints. Visual inspections into the air handlers and the air ducts were also conducted. Subjective assessments (SAs) were utilized to test the response of the business operators. Cost accounting figures, both current and archival data pertaining to air handler maintenance service were retrieved and analysed. Ergonomic interventions were implemented by incorporating applied basic sciences into the rectification work. The original design specifications were modified to produce those for the new make. After new installations were in place, follow-up studies using similar methods (i.e. DOs, SAs, current and archival data) were conducted to assess the effectiveness of the interventions. It was found that the installations were cost effective. The new designs improved human comfort through effective heat removal from the air conditioned

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space. There were also cost savings in the maintenance of the new coil assemblies.

Keywords: *Ergonomics, direct observation, subjective assessment, indoor cooling, maintenance, coil assemblies.*

Nomenclature

fpm : Feet Per Minute
fps : Water Velocity in Tubes (Feet Per Second)
FPS : Feet Per Second
GPM : Chilled water quantity (U.S. Gallons Per Minute)
H : Enthalpy (Btu/lb)
ΔH : Enthalpy Difference (Btu/lb)
L : Fin Length (Inches)
Q : Cooling Load (Btuh)
Q_s : Total Sensible Cooling Capacity (Btuh)
Q_t : Total Cooling Capacity (Btuh)
scfm : Cubic Feet Per Minute At Standard Air Conditions
usGPM: U.S. Gallons Per Minute
W : Finned Width (Inches)
WB : Wet Bulb (^oF)
WTR : The rise in temperature of chilled water
1 Mbh : 1000 Btuh

Introduction

In Malaysia, a tropical country in Asia, coil assemblies in a central air conditioning system serve to provide cooling and dehumidification for the air-conditioned space via air distribution in a system of ductwork and grilles, while heat is carried away to a point where it can be rejected through a medium, such as the refrigerant in a water chiller. In many cases, after almost a decade of air handling operation in the system, coil fins become corroded (resulting from moisture attack), while each air handler's casing and other major components, such as drain-pan, fan assembly, and the associated supporting structures are in fairly good conditions. In such a situation, the coil assemblies are not performing the desired cooling effect. It becomes a difficult task to provide an effective cooling comfort for those human occupants in a building by means of any state-of-the-art maintenance service procedures.

It is a normal practice to replace coil assemblies of the similar manufacture, where exorbitant costs and long delivery periods are inevitable. This paper, however, highlights a contrary to the conventional practice. The intervention exercise included cooling load calculations, and subtle alteration of fin series of other coils having different design features in order to attain better performance from the assemblies, thereby from the improved air handling system as a whole. The brief preliminary findings of the research were presented in Loo and Yeow [1, 2, 3, 4, 5]. This paper delivers the detailed findings.

Method

Procedures

An investigation was initially conducted to capture a general idea of poor indoor cooling suffered by both the business operators and patrons in two shopping complexes. Ergonomics methods were applied to obtain information on those major complaints. These included unstructured interviews [6] conducted among managers, engineers, and selected employees. Those participated in the process in Complex *1* included a maintenance manager, a maintenance engineer and a senior technician, whereas Complex *2* involved a complex manager, a maintenance engineer and a maintenance supervisor. Direct observations (DOs) [7] were conducted on those complaint shoplots by obtaining four temperature readings (from dry bulb psychrometer readings) at chest height at the centre of each shoplot, one obtained in the morning between 10.00 am and 11.00 am, another during lunch hour between 1.00 pm and 2.00 pm, the third obtained between 4.00 pm and 5.00 pm while the fourth in the evening between 7.00 pm and 8.00 pm. Visual inspections into the condition of the entire cooling equipment, and their associated air distribution ductwork and grilles were also conducted to investigate into any abnormality up there, such as damages to ductworks, air leakages, and any abnormality in air discharge to shoplots.

Subjective assessments (SAs) [8] by means of questionnaires were designed. They were tested upon the business operators to further confirm the DOs. Current and archival data [7] were obtained from the maintenance department. These included latest building maintenance methods, procedures and schedules, air handlers history, capacities and specifications, etc. Cost accounting figures pertinent to expenditures on air handler maintenance were also retrieved and analysed to look into the extent of the problems. Ergonomic interventions were duly implemented. Follow-up studies using similar methods were then conducted (i.e. DOs, SAs, current and archival data) to ascertain the effectiveness of the interventions.

Ergonomics Assessment of Air Conditioned Environments

Interviews were conducted with the business operators, one at a time from each affected shoplot, and each interview took about twelve minutes to complete. The interviewer had a good working knowledge of building air conditioning services and hence could understand the subjects' responses easily and able to record them accordingly in the questionnaire.

Interview Participants

6 business operators whose shoplots were served by air handler *AH-1* in complex *1*, and another 10 served by air handler *AH-2* in Complex *2* were interviewed. There were 4 male and 2 female participants in complex *1*, 9 male and 1 female participants in complex *2*.

Analysis

The data obtained from the interview participants were studied for trends of problems circling around the air conditioning service in the shoplots for the two complexes. Temperature readings collected and the visual inspection records from air handling equipment during the DOs were analysed to investigate further the trends. The participants' responses related to shopping patronage and business performance were taken as a major judgment to the magnitude of the cooling problems and the extent of ergonomic improvements, before and after redesigns.

Results

Air conditioned shoplots' problems

All the business operators reported that they suffered much discomfort due to poor indoor cooling, especially from noon hour until the evening each day. 33.3% and 30% from shoplot areas served by *AH-1* and *AH-2* respectively felt that their shoplot environments were comparatively very warm generally, while 66.7% and 70% from the above two shoplot areas complained of warm sensation throughout their business hours. The quality of cooling comfort was rated very poorly by 16.7% of the business operators from Complex *1* and 30% from Complex *2,* while 83.3% from Complex *1* and 70% from Complex *2* rated very poor quality of cooling comfort in their shoplots. The poor level of shopping patronage and business performance tied in fairly closely, with 16.7.% and 40% of the respective business operators in Complexes *1* and *2* complained of very low level of shopping patronage while 16.7% from Complex *1* and 40% from Complex *2* complained of very poor business performance. 33.3% from Complex *1* and 50% from Complex

2 were very unsatisfied with their shoplot air conditioned environments while 66.7% and 50% from the respective two areas indicated their de-satisfaction.

Direct measurement of 6 shoplot temperatures under *AH-1* showed a fairly high average temperature reading of 78.83 ± 0.94 °F (out of 24 readings taken during the stipulated business hours, on a sunny Sunday) which is way out of the range of temperatures for comfort cooling. The same problem is true for the 10 shoplot temperature readings (averagely 78.95 ± 1.03 °F out of 40 readings taken on another Sunday, also sunny day). From the archival data collected, the air handlers in Complexes *1* and *2* had been operating for more than 12 long years. Visual inspections into the condition of *AH-1* and *AH-2* cooling equipment as well as air distribution ductwork and grilles revealed that the major problem came from the corroded fins within the interior of the cooling coils.

Maintenance and Repair Costs

Besides normal maintenance conducted by complex technicians, outsourced chemical cleaning was practiced in these two complexes to ensure clean coil assemblies were used at all times to maintain maximum possible cooling efficiency. This was done (outside normal working hours) by removing a dirty coil assembly from its plant room at night time after shopping hours, thoroughly chemical-cleaned the unit in an open area and installed it back to the associated air handler in the morning of the next business day. This practice no doubt improved the cooling efficiency to a certain extent. *AH-1* cooling coil assembly which was chemically cleaned twice a year costs RM4, 200, while similar cleaning for *AH-2* coil unit conducted trice a year costs RM7, 800.

To repair the air handlers requires exorbitant costs for original spare parts, i.e. new coil assemblies from original suppliers (namely Brand A). The quotations for such a repair were noted to be RM10,000 for *AH-1* and RM14,000 for *AH-2*.

Ergonomic Redesign of Coil Assemblies

As the complex owners were not acceptable to high cost replacement products, they sought ways and means of obtaining low cost alternatives without reverting to the original manufacturers. In such a situation, an alternative approach was proposed. The method involved the redesign of economical coil assemblies (namely Brand B) by incorporating applied basic sciences into ergonomics methods and concepts. The following sections present a series of steps to arrive at the desired results for the central air conditioning systems in the complexes.

Original Air Handlers and Coil Assemblies Specifications

Brand A specifications for both air handlers and their coil assemblies are shown in Table 1 and Table 2. The products are identified as *AH-1* and *AH-2*.

Both air handlers use fins (aluminium) and tubes (copper) for their coils. Their performance has been certified in accordance with ARI Standard 410.

Table 1 Original air handler specifications

Air Handler Tag	***AH - 1***	***AH - 2***
Manufacturer	Brand A	
Overall Dimension	3' 9 ½" x 6' 8" x 9' 8"	4' 6 ½" x 8' 2"x x 9' 4"
Operating Weight (lb.)	1,440	2.460
Material of Casing	GALVANIZED STEEL SHEET	
Type and Thickness of Insulation	1"	
Type of Anti-corrosive Paint	ZINC COAT	
Air Quantity (cfm)	8,340	15,290
Type of Fans	F C CENTRIFUGAL	
Type of Motor	SQUIRREL CAGE	
Motor H.P.	10	25
Motor Speed (rpm)	1440	
Motor Manufacturer	INMACO	
Static Pressure (in wg)	4.5	5.0
Anti-vibrations	1" RUBBER PAD	

Table 2 Original coil assembly specifications

Air Handler Tag	***AH - 1***	***AH - 2***
Manufacturer	Brand A	
Face Area (ft^2)	15.60	28.30
Face Velocity (fpm)	535	540
Type of Coil	ALUMINIUM FIN & COPPER TUBE	
No. of Rows	4	
Fins/Inch	12	12
Air Resistance (in wg)	1.05	1.08
Water Pressure Drop (psi)	3.75	3.3
Chilled Water Quantity	74.4	123.5

(usGPM)		
Leaving Air Conditions (^{0}F)	56.3 /55.4	56.2 / 55.2
Entering Air Conditions (^{0}F)	78 /68	77.4 / 67.1
Total Cooling Capacity (Btuh)	310,180	514,070
Total Sensible Cooling Cap. (Btuh)	169,500	303,000
Maximum Working Pressure	300PSIG	

New Coil Assemblies

Brand B, coil type W which were readily available were utilised, the performance of which has been certified in accordance with ARI Standard 410. All coil assemblies were of similar materials to that of the original.

Coil Assembly Redesigned for *AH-1*

The original cooling load estimated for *AH-1* based on entering and leaving wet bulb (WB) temperatures of 68°F and 55.4°F respectively (Table 2) and a standard air flow rate of 8,340 cfm across the coil face was 335,894 Btuh, by using the equation:

$$Q = \Delta H \times 4.5 \times scfm \qquad (1)$$

where ΔH is the enthalpy difference and scfm is the standard air flow rate (or simply, air quantity) of the system as given in Table 1. Based on this load and a chilled-water flow rate specified for the coil of 74.4 usGPM (Table 2), the rise in temperature of chilled-water (WTR) across *AH-1* coil was 9°F, by using WTR = Q/500 x GPM. This temperature is close to the original design practice of having chilled-water temperature change of 10 °F.

By measuring the internal dimensions of the coil section and making use of the original face area, the number of rows of copper tubes and the number of aluminium fins per inch in the original specifications, a custom-made coil of 36" (L) x 62.5" (W) face area, 4 rows of tubes and 12 fins per inch of fins was determined for cooling load calculations.

From the given usGPM, the tube-side water velocity (fps) was calculated to be 3.43 FPS. Its associated pressure drop across the header was found to be 1.79 ft. H_2O whilst that along the tubes was 2.84 ft. H_2O. Hence the total pressure drop across both header and tubes was estimated at 2.0 psig.

By adhering to the calculated WTR as the basis for coil design based on entering air dry bulb/wet bulb temperatures at 80/67 °F, it therefore followed that at an air velocity of 535 fpm across the coil face (ref. Table 2) and tube-water velocity (fps) of 3.43 FPS, the total cooling capacity (Q_t) was estimated at 302,640 Btuh.

The original coil requirement was specified at 310,180 Btuh which is a higher value than the above. As brand B's capacity was insufficient, consideration for installation of spring turbulators within each tube was made, as this would help to increase the cooling capacity at a rate equivalent to doubling the value of tube velocity. By similar calculation, again, the new Q_t was estimated at 341,640 Btuh which is approximately 10 % higher that specified.

The corresponding coil-water flow rate, air resistance and total sensible cooling capacity (Q_s) were subsequently determined at 76.6 usGPM, 0.84 in. H_2O (refer Figure 1) and 196,361 Btuh respectively as shown in Table 3.

Coil Assembly Redesigned for *AH-2*

By adopting similar mode of calculation, WTR of 9.3 ^oF was obtained. By measurement, it was found that a custom-made coil of 42" (L) x 97" (W) face area was suitable for further load checking. The numbers of rows and fins per inch remained the same as the original specifications. Q_t was estimated at 588,640 Btuh (100%) while the original requirement was specified at only 514,070 Btuh (87%).

In this particular case, Q_t was more than sufficient when compared with that of the original. Air resistance and Q_s were thus determined accordingly as shown in Table 3.

Table 3 Revised coil assembly specifications (after ergonomic redesign)

Air Handler Tag	*AH - 1*	*AH - 2*
Manufacturer	Brand B	
Coil Dimenstion (W x L in^2)	36 x 62.5	42 x 97
Face Velocity (fpm)	535	540
Type of Coil	ALUMINIUM FIN & COPPER TUBE	
No. of Rows	4	
Fins/Inch	12	10
Air Resistance (in wg)	0.84	0.85
Water Pressure Drop (psi)	15.9	5.1
Chilled Water Quantity (usGPM)	76.6	116.9
Leaving Air Conditions (^0F)	56.3 / 55.4	56.2 / 55.2
Entering Air Conditions (^0F)	78 / 68	77.4 / 67.1
Air Quantity (cfm)	8,340	15,290
Total Cooling Capacity (Btuh)	341,640	588 640
Total Sensible Cooling Cap. (Btuh)	196.360	351,700
Maximum Working Pressure	300PSIG	
Turbulators	YES	NO

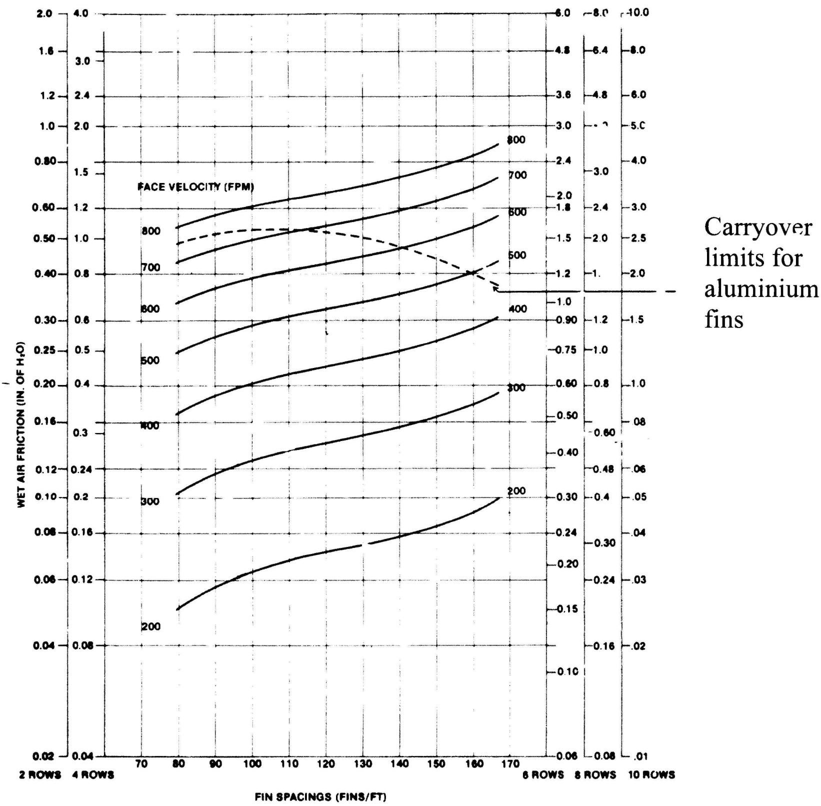

Figure 1 Wet air friction and moisture carryover limits (Chart by TRANE U.S.)

Post Surveys on the Effectiveness of Redesigned Coil Assemblies

Immediately after the installation of the new redesigned coil assemblies, the business operators as well as the patrons experienced an improvement in shoplots air conditioning service served by *AH-1* and *AH-2*. Among the business operators, 16.7% from Complex *1* and 20% from Complex *2* reported their shoplots were very cold. 4 months after, the results of post survey were recorded and compared with the previous survey results. The improvements were still significant. Direct measurement of 6 shoplot temperatures under *AH-1* showed a fairly lower average temperature reading of 74.58 ± 0.94 °F (out of 24 readings taken during the stipulated business hours on a sunny Sunday) which is within the range of temperatures for comfort cooling. The same improvement was true for the 10 shoplot temperature readings (averagely 74.55 ± 1.04 ^{o}F out of 40 readings taken on another Sunday sunny day).

Discussion

Improvements

Comparing SAs and DOs before and after interventions, there were improvements in human cooling comfort in shoplots served by *AH-1 and AH-2 in* the two complexes. Both places experienced a significant increase in the level of patronage as a result of a significant improvement in cooling quality in the shoplots. Likewise, business performance improved in tandem with better cooling comfort. Moreover, the business operators were satisfied with their shoplot air conditioning environments, thus assuring successful intervention exercises conducted.

Benefits of ergonomics investment

Table 4 Maintenance and repair costs comparison

Maintenance

Air Handler Coil Assembly	Chemical Cleaning (RM)		Saving (RM)
	Before Intervention	After Intervention	
AH-1	4,200 / year	0	4,200 / year
AH-2	7,800 / year	0	7,800 / year

Repair

Air Handler Coil Assembly	Original Coil Assembly (RM)	Redesigned Coil Assembly (RM)	Saving	
			(RM)	(%)
AH-1	10,000	6,000	4,000	40.0
AH-2	14,000	8,800	5,200	37.1

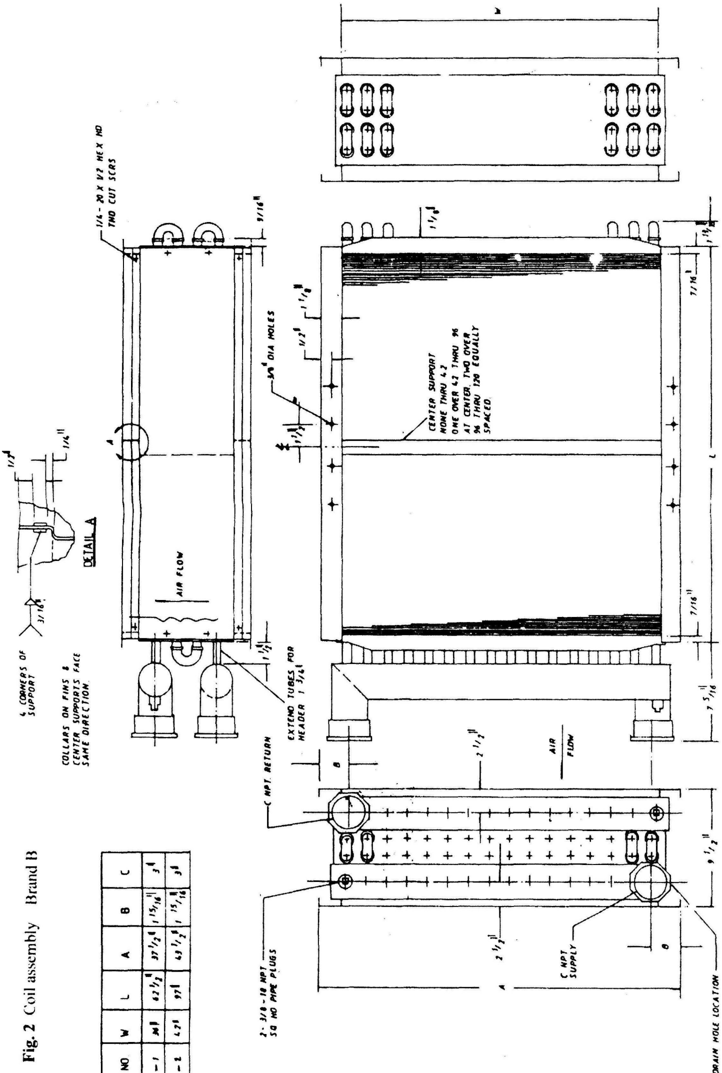

Fig. 2 Coil assembly Brand B

TAG NO	W	L	A	B	C
AH-1	30"	62 1/2"	37 1/2"	1 15/16"	3"
AH-2	42"	97"	63 1/2"	1 15/16"	3"

From the cost accounting archival records of the two shopping complexes, approximately RM6, 000.00 was spent in installing new redesigned coil assembly for *AH-1* while RM8, 800.00 was spent for that of *AH-2* (Table 4). When comparing with expensive original coil assembly installations, there were savings of 40.0% for *AH-1* and 37.1% for *AH-2*. As chemical cleaning is absolutely not required for new coil assemblies of higher cooling loads, archival records for *AH-1* and *AH-2* cost centres one year after new installation showed cost savings of RM4, 200.00 and RM7, 800.00 respectively for no cost incurred in chemical cleaning.

In the absence of heat waves (due to effective indoor cooling) in the shoplots concerned during business hours, patrons were no longer turned away from shopping spree, even during hot sunny days. The complex management did not need to demand lower prices from original coil suppliers, but could turn to such a lower cost alternative with substantial savings. The need to carry out chemical cleaning for defective coils at substantial costs was also eliminated.

Conclusions

The low cost ergonomic redesign of coil assemblies presented in the study was cost effective. The technique has its commercialization value in terms of consultancy/redesign services to building owners, maintenance managers, M&E Managers as well as air conditioning contractors in high rise buildings and large complexes using central station air handling systems. Judging from the usability of a series of systematic steps in ergonomic redesigns presented herein, commercial software can well be developed for entering both the old air handler and its coil specifications to generate the new design specifications to achieve the desired results.

Acknowledgements

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JOURNAL OF MECHANICAL ENGINEERING (JMechE)

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Journal of Mechanical Engineering (formerly known as Journal of Faculty of Mechanical Engineering) or JMechE, is an international journal which provides a forum for researchers and academicians worldwide to publish the research findings and the educational methods they are engaged in. This Journal acts as a vital link for the mechanical engineering community for rapid dissemination of their academic pursuits.

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ABSTRACT

The first section of the manuscript should be an abstract, where the aims, scope and conclusions of the papers are shortly outlined, normally between 200 and 300 words. TNR-10 italic

Keywords: maximum 5 keywords.

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Leave one blank line between the heading and the first line of the text. No indent on the first para after the title; 10 mm indent for the subsequent para. At the end of the section, leave two blank lines before the next section heading. The text should be right and left justified. The recommended font is Times New Roman, 10 points. In 152 mm x 277 mm paper size, the margins are: left and upper: 22 mm each; right: 20 mm, lower: 25 mm.

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$$y = A + Bx + Cx^2 \quad (1)$$

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Examples of references:

[1] M. K. Ghosh and A. Nagraj, "Turbulence flow in bearings," Proceedings of the Institution of Mechanical Engineers 218 (1), 61-4 (2004).
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