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# APPENDIX A

## LAYOUT OF THE FACTORY

Descriptions:

1. Security
2. Cooling Tower
3. Main Transformer
4. Elec. Substation
5. Air Compressors
6. Chillers
7. Boilers
8. Maintenance Shop
9. Fuel Tank
10. Adm. office
11. Polymerization
12. Spinning & Take Up
13. Draw-Twisting
14. Warehouses
15. Dormitories
16. Dining Room
17. Waste Water Pools

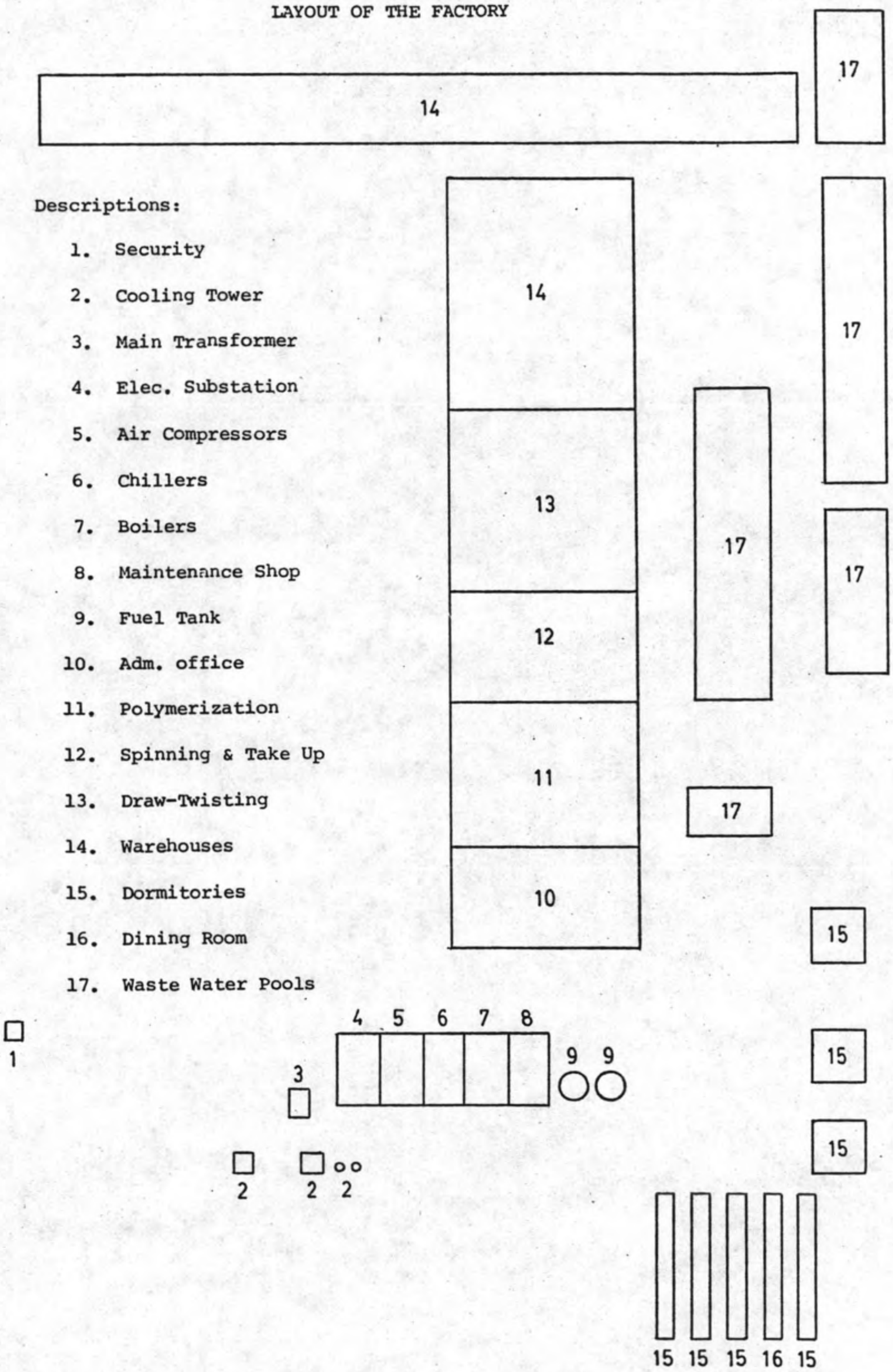



Figure A.1 Layout of the Factory

# APPENDIX B

## ELECTRICAL ENERGY AUDIT

Table B.1 A Company-Wide Electrical Energy Audit (March 25, 1986)

| Equipment | Nameplate | | Measured | | | Hour per Day | kWh per Day | Remark |
|---|---|---|---|---|---|---|---|---|
| | HP | A | kW | A | V | | | |
| Substation 1 for the Polymerization Section (1 st, 2 nd and 3 rd Floors) | | | | | | | | |
| 1. Finish. Tower Heater | 8x20.4* | 8x40 | 81.6 | 14.2 | - | 24 | 1958 | Run 4 sets |
| 2. Extrus. Vapor. Heater | 2x18* | 2x36 | 24 | 26 | - | 24 | 576 | Run 1-2 sets |
| 3. Preheater | 4x72* | 4x143 | 120.9 | 412 | - | 24 | 2901 | Dowterm |
| 4. Transfer Heater | 2x24* | 2x48 | 31.2 | 66 | - | 24 | 749 | Vaporizer |
| 5. Monomer Tank Agitator | 2x1.0 | 2x1.7 | 1.4 | 2x1.6 | - | 24 | 34 | |
| 6. Blend. Tank Agitator | 1.0 | 1.7 | 0.7 | 1.6 | - | 8 | 6 | |
| 7. Monomer Transfer Pump | 3x1.5 | 3x3.7 | 1.4 | 2x2.2 | - | 24 | 34 | One standby |
| 8. Quench Water Pump | 2x5 | 2x8.4 | 1.8 | 5.4 | 389 | 24 | 43 | One standby |
| 9. Palletizer Drive | 2x7.5 | 2x26 | 5 | 2x11.5 | - | 24 | 120 | |
| 10. Finish. Tower Drive | 2x5 - | 2x26 | 2.46 | 2x8.6 | - | 24 | 59 | |
| 11. Pull Roll Drive | 2x .75 | 2x7.4 | 0.36 | 2x2.4 | - | 24 | 9 | |
| 12. Condensate Pump | 1.0 | 3.3 | 0.45 | 2.0 | - | 10 | 5 | |
| Subtotal | | | 270 | | | 24 | 6494 | kW=(6494)/24 |
| Substation 1 for the Spinning Section (3 rd Floor) | | | | | | | | |

Table B.1 (Con't)

| Equipment | Nameplate | | Measured | | | Hour per Day | kWh per Day | Remark |
|---|---|---|---|---|---|---|---|---|
| | HP | A | kW | A | V | | | |
| 13. Spinning Block Heater | 6x24* | 6x48 | 144 | 6x9 | - | 24 | 3456 | |
| 14. Spinning Manifold Heater | 6x9* | 6x18 | 54 | 6x13.6 | - | 24 | 1296 | |
| 15. Preheater Transformer | 15kVA | 22.5 | 51.5 | - | - | 24 | - | |
| Subtotal | | | 198 | | | 24 | 4752 | |
| Substation 1 for the Utility Section (1 st Floor) | | | | | | | | |
| 16. Condenser Pump-2 π‡ | 2x60 | 2x87 | 41.5 | 74.2 | 380 | 24 | 996 | |
| 17. Deep Well Pump π | 2x40 | 2x60.5 | 24.8 | 43.6 | 375 | 20 | 496 | |
| 18. Boiler Water Feed Pump π | 2x20 | 2x31 | 15 | 19 | - | 6 | 90 | Start twice/min |
| 19. Fuel Oil Feed Pump π | 2x0.75 | 2x1.2 | 0.56 | 0.6 | - | 24 | 13 | |
| 20. Fuel Transfer Pump π | 2x3 | 2x4.5 | 1.5 | 3 | - | 12 | 18 | |
| 21. Force Draft Fan π | 2x7.5 | 2x22.5 | 1.09 | 7.53 | 383 | 24 | 26 | |
| 22. Condenser Pump-12 ‡ | 55 | 73.9 | 37.5 | 64.5 | 385 | 24 | 900 | |
| Subtotal | | | 106 | | | 24 | 2539 | |
| Substation 2 for the Spinning and Take Up Sections (1 st, 2 nd, and 3 rd Floors) | | | | | | | | |
| 23. Extruder Heater | 6x35* | 6x70 | 78.3 | 6x26.1 | - | 24 | 1880 | |
| 24. Extruder Drive | 6x40 | 6x60 | 110.4 | 6x40.6 | - | 24 | 2650 | |

Table B.1 (Con't)

| Equipment | Nameplate | | Measured | | | Hour per Day | kWh per Day | Remark |
|---|---|---|---|---|---|---|---|---|
| | HP | A | kW | A | V | | | |
| 25. Metering M/G Set | 2x75 | 2x116 | 89.52 | 2x46 | - | 24 | 2148 | |
| 26. Godet M/G Set | 2x40 | 2x69.4 | 47.8 | 2x32 | - | 24 | 1147 | |
| 27. Metering Inverter | 75 | 129 | 44.8 | 30 | - | 24 | 1075 | |
| 28. Godet Inverter | 40 | 91.2 | 23.87 | 11.3 | - | 24 | 573 | |
| 29. Silicone Circulate Pump | 0.75 | 1.9 | 0.56 | 1.1 | - | 24 | 13 | |
| 30. Spinning ASWR Pump | 2x15 | 2x23.6 | 16.12 | 15.83 | 383 | 24 | 386 | |
| 31. Quench Air Fan | 60 | 82 | 35.8 | 62.7 | - | 24 | 859 | |
| 32. Take Up Air Fan | 25 | 37.5 | 14.9 | 27.9 | - | 24 | 358 | |
| 33. Finish. Oil Agitator | 0.25 | 0.5 | 0.19 | 0.5 | - | 24 | 5 | |
| 34. Finish. Oil Trans. Pump | 3x0.75 | 3x1.5 | 1.68 | 3x1.1 | - | 24 | 40 | |
| 35. Emulsion Wheel Drive | 3x0.5 | 3x2.5 | 1.12 | 3x1 | - | 24 | 27 | |
| 36. Finish. Oil Circ. Pump | 0.75 | 1.5 | 1.12 | 1.3 | - | 24 | 27 | |
| 37. Finish. Oil Trans. Pump | 2 | 3.4 | 1.5 | 1.2 | - | 24 | 36 | |
| 38. Fan Coil Unit | 10 | 15 | 6.14 | 13.5 | 384 | 24 | 147 | |
| 39. Take Up Drive Tranformer | 4x45 kVA | 274 | | 4x32 | - | 24 | | |
| Subtotal | | | 474 | | | 24 | 11371 | |
| Substation 3 for the Draw-Twisting Section (1 st and 2 nd Floor) | | | | | | | | |

Table B.1 (Con't)

| Equipment | Nameplate | | Measured | | | Hour per Day | kWh per Day | Remark |
|---|---|---|---|---|---|---|---|---|
| | HP | A | kW | A | V | | | |
| 40. Draw-twister 1-15 | 15x31.5 | 15x46.4 | 206 | 15x27.1 | - | 18 | 3708 | Hour/day |
| 41. Draw-twister 16-17 | 2x55 | 2x85 | 45.3 | 2x47 | - | 18 | 815 | are based on data of |
| 42. Back Winder | 10 | 15 | 1.69 | 3.4 | - | 15 | 25 | February 1986 |
| 43. Draw-twist. AWSR Fan | 125 | 187 | 34.9 | 70 | - | 24 | 838 | |
| 44. Spray Water Pump | 40 | 60 | 20.2 | 36.8 | 385 | 24 | 485 | |
| Subtotal | | | 245 | | | 24 | 5871 | |
| Substation 3 for the Polymerization Section | | | | | | | | |
| 45. Aerator | 2x20 | 2x30 | 13.8 | 25.5 | 387 | 12 | 166 | One standby |
| 46. Lift | 20 | - | 8.9 | - | - | 6 | 54 | |
| Subtotal | | | 9 | | | 24 | 220 | |
| Substation 3 for the Spinning Section (3 rd Floor) | | | | | | | | |
| 47. Burn-out Blower 1 | 3 | 4.5 | 1.3 | 2.6 | - | 1 | 1.3 | |
| 48. Burn-out Blower 2 | 0.3 | 0.5 | 0.15 | 0.3 | - | 1 | 0.15 | |
| 49. Burn-out Heater | 27* | 54 | 14.88 | 37 | - | 1 | 14.88 | |
| Subtotal | | | 1 | | | 24 | 16 | |
| Substation 3 for Lighting | | | 57 | | | 24 | 1368 | See Appendix C |

Table B.1 (Con't)

| Equipment | Nameplate | | Measured | | | Hour per Day | kWh per Day | Remark |
|---|---|---|---|---|---|---|---|---|
| | HP | A | kW | A | V | | | |
| Substation 4 for the Polymerization Section (1 st, 2 nd, 3 rd, 4 th Floors) | | | | | | | | |
| 50. Delustering Pump | 3 | 4.5 | 1.25 | 2.5 | - | 24 | 30 | |
| 51. Kady Mill | 30 | 44.5 | 15.7 | 31.2 | 386 | 3 | 47 | Run |
| 52. Sand Mill Main Drive | 15 | 24.1 | 4 | 8.5 | - | 3 | 12 | 4 times/wk |
| 53. Delust. Mix Tank Agitator | 0.25 | 0.5 | 0.08 | 0.2 | - | 3 | 2 | 5 hrs/run |
| 54. $TiO_2$ Transfer Pump | 1.5 | 2.25 | 0.75 | 1.5 | - | 3 | | (7 a.m.-3 P.m.) |
| 55. Delust. Circ. Tank Agitator | 0.25 | 0.5 | 0.08 | 0.2 | - | 24 | 2 | |
| 56. Dryers | 4x20 | 4x30.8 | 13 | 4x9.7 | - | 15 | 195 | |
| 57. Melting Tank Pump | 5.5* | 10.9 | 2.8 | 5.4 | - | 3 | 8 | 25 min/bat. |
| 58. Blend. Transfer Pump | 5.5* | 10.9 | 1.5 | 3.0 | - | 3 | 5 | 2 bat/shift |
| 59. Raw Chip Trans. Blower | 2x5 | 2x9.3 | 5.1 | 2x7.17 | - | 24 | 122 | |
| 60. Hot Well Pump | 2x15 | 2x45 | 8.4 | 15.1 | 383 | 24 | 202 | One standby |
| 61. Chilled Water Pump-2‡ | 2x40 | 2x61 | 28.4 | 49.8 | 385 | 24 | 682 | One standby |
| 62. Miscut Chip Remover | 2x1 | 2x1.5 | 1.26 | 2x1.27 | - | 24 | 30 | |
| 63. Raw Chip Rotary Feeder | 2x0.75 | 2x1.7 | 1 | 2x1.6 | - | 24 | 24 | |
| 64. Monomer Recov. Feed Pump | 2x3 | 2x5.35 | 1.1 | 2.5 | 391 | 24 | 26 | One standby |
| 65. CHPF‡ | 5 | 8.5 | 2.1 | 4.8 | - | 24 | 50 | |

Table B.1 (Con't)

| Equipment | Nameplate | | Measured | | | Hour per Day | kWh per Day | Remark |
|---|---|---|---|---|---|---|---|---|
| | HP | A | kW | A | V | | | |
| 66. Air Scrubber | 1.5 | 2.8 | 0.48 | 1.2 | - | 24 | 12 | |
| 67. Dry Chip Trans. Blower | 40 | 60.6 | 6.16 | 21.9 | 385 | 4 | 25 | 4 bat./day |
| 68. Demineral. Water Pump | 3 | 4.7 | 1.5 | 3.2 | - | 8 | 12 | |
| 69. Crush Mill | 5 | 7.5 | 1.3 | 2.6 | - | 8 | 11 | 2-3 batches |
| 70. Lactam Exhaust Fan | 0.75 | 1.5 | 0.45 | 1.2 | - | 8 | 4 | per shift |
| 71. Extract. Tower Lower Pump | 3x3 | 3x5.35 | 1.2 | 2x2.8 | - | 24 | 29 | One standby |
| 72. Monomer Circulate Pump | 15 | 22.5 | 6.45 | 15.2 | 384 | 24 | 155 | |
| 73. Monomer Circulate Pump | 2x10 | 15 | 5.5 | 11 | - | 24 | 132 | One standby |
| 74. Centrifuge Rotor | 2x3 | 2x9 | 1.02 | 2x2.1 | - | 24 | 25 | |
| 75. Centrifuge Pusher | 2x2 | 2x6 | 1.1 | 2x2.2 | - | 24 | 26 | |
| 76. Dry Chip Trans. Blower | 10 | 17.5 | 4.77 | 11.2 | - | 12 | 57 | |
| 77. Monomer Recov. Water Pump | 5 | 7.9 | 1.94 | 4.1 | - | 12 | 23 | |
| 78. Vacuum Pump | 10 | 14.8 | 2.53 | 5 | - | 5 | 13 | |
| 79. Ext. Rotary Feeder | 2x1.5 | 2x3.75 | 1.9 | 2x3.2 | - | 24 | 46 | Ext. stands |
| 80. Ext. Upper Pump | 2 | 3.8 | 1.07 | 3.2 | - | 24 | 26 | for Extraction |
| 81. Ext. Upper Pump | 3 | 4.7 | 1.57 | 3.4 | - | 24 | 38 | Tower. |
| Subtotal | | | 86 | | | 24 | 2071 | |

Table B.1 (Con't)

| Equipment | Nameplate | | Measured | | | Hour per Day | kWh per Day | Remark |
|---|---|---|---|---|---|---|---|---|
| | HP | A | kW | A | V | | | |
| <u>Substation 4 for the Office Building (1 st Floor)</u> | | | | | | | | |
| 82. Chiller Compressor | 40 | 61 | 19.57 | 40.4 | 380 | 9 | 176 | Office hour: |
| 83. Chilled Water Pump | 7 | 12.2 | 5.5 | 12.2 | - | 9 | 50 | 8 a.m.-5 p.m. |
| 84. Condenser Pump | 5 | 8.5 | 3.73 | 9.3 | - | 9 | 34 | Sunday closed |
| 85. Cooling Tower Fan | 3 | 4.5 | 2.23 | 4.5 | - | 9 | 20 | |
| <u>Subtotal</u> | | | 10 | | | 24 | 280 | $kW=\frac{(280)(6)}{(24)(7)}$ |
| <u>Substation 4 for the Utility Section</u> | | | | | | | | |
| 86. Demineral. Supply Pump | 2x5 | 2x7.9 | 2.83 | 6 | - | 8 | 23 | One standby |
| 87. Chilled Water Pump 1-2** | 2x10 | 2x15.8 | 7.59 | 13.52 | 382 | 24 | 182 | One standby |
| 88. Brine Chiller** | 2x75 | 2x104 | 32.3 | 57.4 | 374 | 24 | 775 | One standby |
| 89. Brine Chiller** | 100 | 143 | 44.7 | 102.2 | 383 | 24 | 1073 | |
| 90. Condenser Pump 1-2** | 2x40 | 2x60 | 28.5 | 50.1 | 383 | 24 | 684 | One standby |
| 91. Cooling Tower Fan 1-2** | 2x5 | 2x7.5 | 2.32 | 7.3 | - | 24 | 56 | |
| 92. Condenser Pump 12‡ | 55 | 73.9 | 41.2 | 70.6 | 382 | 24 | 989 | |
| 93. Cooling Water Pump -1‡ | 3 | 3.5 | 1.13 | 3.5 | - | 12 | 42 | |
| 94. Cooling Water Pump -2‡ | 2 | 3 | 0.97 | 3 | - | 12 | 36 | |

Table B.1 (Con't)

| Equipment | Nameplate | | Measured | | | Hour per Day | kWh per Day | Remark |
|---|---|---|---|---|---|---|---|---|
| | HP | A | kW | A | V | | | |
| 95. Cooling Tower Fan 21-22‡ | 2x20 | 2x60 | 28.29 | 49.7 | 387 | 24 | 679 | |
| 96. Air Compressor** | 3x108 | 3x151 | 54.5 | 101.5 | 384 | 24 | 1308 | Two standby |
| 97. Centrifugal Chiller‡ | 2x600 | 2x95 | 306 | 63 | - | 24 | 7344 | 3.3 kV |
| 98. Cooling Tower Fan-1‡ | 25 | 58 | 3.15 | 10.1 | - | 24 | 76 | |
| 99. Chiller Transformer | 2x2 kVA | 6 | - | - | - | 2 | - | One standby |
| 100. Chem. Lab. Transformer | 45 kVA | - | - | - | - | 8 | - | 8 a.m.-4 p.m. |
| Subtotal | | | 553 | | | 24 | 13,267 | |
| Grand-total | | | 2009 | | | 24 | 48,209 | |

* The nameplate capacity is expressed in kilowatt.

** See Figure 6.5 for the schematic illustration.

π This equipment possesses one standby.

‡ See Figure 6.1 for the schematic illustration.

APPENDIX C

LIGHTING AUDIT

Table C.1 A Company-Wide Lighting Audit (March 18, 1986)

| Areas | No.of Lamp | | Total Watts | Hour per Day | Measured Lux | CIE Std ‡ Lux | Remark |
|---|---|---|---|---|---|---|---|
| | 40W | ES ** | | | | | |
| Central Office Building | | | | | | | |
| Main Section | | | | | | | |
| 1. Plant Manager | 2 | - | 106 | 8 | 300 | 500-750 | Wattage of this |
| 2. Typist | 2 | - | 106 | 8 | 480 | 500 | table is the wattage |
| 3. Accountant | 2 | - | 106 | 8 | 1200 | 500 | of the lamp plus |
| 4. Others | 6 | 9 | 777 | 8 | 280-560 | 500 | that of its ballast |
| | | | | | | | (approx. 13 W). |
| Middle Section | | | | | | | |
| 5. Nursing Room | 2 | - | 106 | 24 | 110 | 300 | |
| 6. Exec. Manager | 2 | 4 | 310 | 8 | 800 | 500-750 | |
| Clerk Room | | | | | | | |
| 7. Front Zone | - | 2 | 102 | 8 | 100 | 500 | |
| 8. Middle Zone | - | 4 | 204 | 8 | 180 | 500 | |
| 9. Back Zone | - | 8 | 408 | 8 | 230-360 | 500 | |
| Subtotal | 16 | 27 | 2225 | | | | kW (avg.) = 0.81 or 1.0 |
| Polymerization Building | | | | | | | |

Table C.1 (Con't)

| Areas | No.of Lamp | | Total Watts | Hour per Day | Measured Lux | CIE Std Lux | Remark |
|---|---|---|---|---|---|---|---|
| | 40W | ES | | | | | |
| 1 st Floor | | | | | | | |
| 10. Work Shop | 4 | 7 | 569 | 24 | 130-250 | 300-750 | May off the unused |
| 11. Toilet | 1 | - | 53 | 24 | 97 | 100 | |
| 12. 1 st Row (East) | - | $3^{\pi}$ | 1200 | 12 | 50-100 | 150 | |
| 13. 2 nd Row | - | 2 | 102 | 24 | 87-115 | 150 | |
| 14. 3 rd Row | 2 | 1 | 157 | 12 | 80-130 | 150 | |
| 15. Screening | 1 | 3 | 206 | 24 | 150 | 150 | |
| 16. $TiO_2$ Room | - | 1 | 51 | - | 145 | 500 | Uncertain time |
| 17. 1000 kVA Tr. Rm. | 6 | - | 318 | 12 | 130 | 150 | |
| 18. Security | - | 2 | 102 | 12 | 200 | 150 | |
| 19. 4 th Row | 1 | 4 | 257 | 24 | 145-155 | 150 | |
| 20. Laboratory | 3 | 14 | 873 | 8 | 300-450 | 500 | May off the unused. |
| 21. Stairway 1-2 | 4 | - | 212 | 12 | 87 | 100 | |
| 22. Front Door | 3 | 2 | 261 | 12 | 120 | 100 | |

Table C.1 (Con't)

| Areas | No.of Lamp | | Total | Hour per Day | Measured | CIE Std | Remark |
|---|---|---|---|---|---|---|---|
| | 40W | ES | Watts | | Lux | Lux | |
| <u>2 nd Floor</u> | | | | | | | |
| 23. Toilet | 1 | - | 53 | 24 | 135 | 100 | 12 hrs is enough. |
| 24. Lift Area | 4 | - | 212 | 24 | 80 | 150 | |
| 25. Crush Mill | 31 | - | 1643 | 4 | 450 | 300-500 | |
| 26. Cutter | 18 | 5 | 1209 | 24 | 520 | 500 | |
| 27. Wet Chip | - | $3^{\pi}$ | 1200 | 12 | 250 | 150 | |
| 28. Air Washer | - | $1^{\pi}$ | 400 | 12 | 205 | 150 | |
| <u>3 rd Floor</u> | | | | | | | |
| 29. Extract. Tower | - | $5^{\pi}$ | 2000 | 12 | 312 | 300 | |
| 30. Instrument Room | 1 | $9^{\pi}$ | 3653 | 12 | 440-500 | 750 | Local light. available |
| 31. Control Room | 1 | 5 | 308 | 24 | 160-550 | 500 | |
| 32. Heater Room | 12 | - | 636 | 12 | 145 | 150 | |
| 33. Toilet | - | 1 | 51 | 24 | 120 | 100 | 12 hrs is enough. |

Table C.1 (Con't)

| Areas | No.of Lamp | | Total | Hour per | Measured | CIE Std | Remark |
|---|---|---|---|---|---|---|---|
| | 40W | ES** | Watts | Day | Lux | Lux | |
| <u>4 th Floor</u> | | | | | | | |
| 34. Lift Area | 1 | 1 | 104 | 12 | 87 | 150 | |
| 35. Extract. Tower | - | $1^{\pi}$ | 400 | 12 | 135 | 150 | |
| 36. Finish. Tower | - | 1 | 51 | 12 | 98-166 | 150 | |
| <u>5 th Floor</u> | | | | | | | |
| 37. Lift Area | - | 2 | 102 | 12 | 94 | 150 | |
| 38. Dry Chip | - | $1^{\pi}$ | 400 | 12 | 120 | 100 | |
| <u>Subtotal</u> | 94 | $51, 23^{\pi}$ | 16,783 | | | | kW(avg.) = 9.18 or 10.0 |
| <u>Spinning and Take-Up Building</u> | | | | | | | |
| <u>1 st Floor</u> | | | | | | | |
| 39. Toilet | - | 5 | 255 | 24 | 100-280 | 150 | 2 may be removed |
| 40. Corridor | 2* | 2* | 92 | 24 | 97 | 100 | |
| 41. Take Up Room | 8* | 158 | 8250 | 24 | 120-520 | 500 | |
| 42. Core Storage | - | 9 | 459 | 24 | 33-89 | 30 | 3 may be removed |

Table C.1 (Con't)

| Areas | No.of Lamp | | Total Watts | Hour per Day | Measured Lux | CIE Std Lux | Remark |
|---|---|---|---|---|---|---|---|
| | 40W | ES | | | | | |
| 2 nd Floor | | | | | | | |
| 43. Spinning | 15 | 36 | 1836 | 24 | 200-360 | 500-750 | |
| 44. M/G Set | 4 | 5 | 467 | 24 | 30-345 | 150 | |
| Office | | | | | | | |
| 45. Yongyut-Vichai | - | 4 | 204 | 18 | 145-280 | 500 | Improvement is |
| 46. Adisorn | - | 2 | 102 | 18 | 1150 | 500 | possible from botn |
| 47. Nikom-Madam | - | 3 | 153 | 18 | 370-505 | 500 | relamping and |
| 48. Corridor | 7 | 3 | 524 | 24 | 100-200 | 100 | providing some |
| 3 rd Floor | | | | | | | more switches. |
| 49. Extruder | 7 | 16 | 1187 | 24 | 80 ππ | 100 | Can be off by day |
| 50. Beam Control | 8 | - | 424 | 24 | 145-155 | 150-300 | |
| 51. Burn Out Room | - | 4 | 164 | 6 | 70-150 | 150 | |
| Subtotal | 41,10* | 245,2* | 14,117 | | | | kW (avg.)=13.88 or 14.0 |
| Draw-Twisting Building | | | | | | | |

Table C.1 (Con't)

| Areas | No.of Lamp | | Total | Hour per Day | Measured | CIE Std | Remark |
|---|---|---|---|---|---|---|---|
| | 40W | ES | Watts | | Lux | Lux | |
| 52. Draw-twister | 56 | 327 | 19645 | 24 | 200-500 | 300-750 | |
| 53. Pathway | 13 | 13 | 1352 | 24 | 50-180 | 100 | |
| 54. Back Winder | 1 | 10 | 563 | 24 | 200 | 500 | |
| 55. Box Storage | 4 | - | 212 | 24 | 80 | 75 | May be off by day |
| 56. Textile Lab | 10 | 19 | 1499 | 16 | 240-370 | 500 | |
| 57. Maintenance | 1 | 14 | 767 | 8 | 220-400 | 500 | |
| 58. Packing | 17 | 34 | 2635 | 24 | 150-240 | 300-500 | May be off at night |
| <u>Subtotal</u> | 102 | 417 | 26,673 | | | | kW(avg.)=25.66 or 26.0 |
| <u>Utility Building</u> | | | | | | | |
| 59. Boiler House | 7 | 19 | 1340 | 12 | 167 | 150-300 | |
| 60. Chiller Room | 17 | 9 | 1360 | 12 | 155 | 150-300 | |
| 61. Compressor Room | 6 | 4 | 522 | 12 | 149 | 150-300 | |
| 62. Generator Room | 12 | - | 636 | 12 | 135 | 150-300 | |
| 63. Repair. Shop | 1 | 1 | 104 | 12 | 83 | 150-300 | |
| 64. Dining Room | 1 | 10 | 563 | 12 | 120 | 150 | |

Table C.1 (Con't)

| Areas | No.of Lamp | | Total | Hour per Day | Measured Lux | CIE Std Lux | Remark |
|---|---|---|---|---|---|---|---|
| | 40W | ES | Watts | | | | |
| 65. Others | 3 | 16 | 975 | 12 | 80 | - | For securities, etc. |
| Subtotal | 47 | 59 | 5500 | | | | kW(avg.)= 2.75 or 3.0 |
| 66. Dormitories | 168 | - | 8904 | 8 | - | - | kW(avg.)= 2.97 or 3.0 |
| Grand-total | 300 | 799 | 56649 | | | | kW(avg.)= 57.0 |

* The wattage of this lamp is 20

** "ES" is the lamp of energy saving type with a wattage of approx. 38 W.

‡ See Appendix D for more details.

π This is a high pressure sodium (HPS) lamp with a wattage of 400 each.

ππ Day lighting.

APPENDIX D

Table D.1 Standard Service Illumination

| Area/Activity | Standard Service Illuminance (lux) |
|---|---|
| **General building areas** | |
| Circulation areas, corridors | 100 |
| Stairs, escalators | 150 |
| Cloak rooms, toilets | 150 |
| Stores, stockrooms | 150 |
| **Assembly shops** | |
| Rough work: heavy machinery assembly | 300 |
| Medium work: engine assembly, vehicle body assembly | 500 |
| Fine work: electronic and office machinery assembly | 750 |
| Very fine work: instrument assembly | 1500 |
| **Textile industries** | |
| Bale breaking, carding, drawing | 300 |
| Spinning, winding, reeling, combing, dyeing | 500 |
| Beaming, spinning (fine counts), twisting, weaving | 750 |
| Sewing, burling, inspection | 1000 |
| **Clothing factories** | |
| Sewing | 750 |
| Inspection | 1000 |
| Pressing | 500 |
| **Offices** | |
| General offices, typing, computer rooms | 500 |
| Deep-plan general offices | 750 |
| Drawing offices | 750 |
| Conference rooms | 500 |
| **Homes and hotels** | |
| *Homes:* | |
| Bedrooms | |
| General | 50 |
| Bed-head | 200 |
| Bathrooms | |
| General | 100 |
| Shaving, make-up | 500 |
| Living-rooms | |
| General | 100 |
| Reading, Sewing | 500 |
| Stairs | 100 |
| Kitchens | |
| General | 300 |
| Working areas | 500 |
| Work room | 300 |
| Nursery | 150 |

Source: International Commission for Illumination (CIE)

# APPENDIX E

## ENERGY SYSTEM MAINTENANCE PROGRAM

An effective maintenance program always pays off in lower energy costs, higher equipment availability and lower specific energy consumption. A successful maintenance program can generally be created by using a three-phase approach, including analysis, action, and monitoring.

The first phase, analysis, will consist the following steps:

1. Collect and analyze background data to find the total amount of potential energy cost saving. This step is considered as a process in the energy audit.

2. Examine each system to find where initial repairs can significantly decrease energy consumption and costs. The facility of this factory can be classified into eight major systems as shown in Table E.1. Portable instruments are necessary in this step. Table 2.12 provides useful instruments for maintenance auditors. In the selection of people to do the on-site inspection, line management personnel from each relevant area must be included because a maintenance audit by an external person will bring up questions that cannot be answered by anyone other than line personnel, and can also evaluate the operational feasibility of some suggestions at the time of the audit.

3. Estimate the cost and importance of major repairs.

4. List routine maintenance tasks along with times, frequencies, and skill and equipment requirements. The list, preferably on a 3x5

Table E.1 The Major Energy Systems for the Maintenance Program

| System | Maintenance Activity |
|---|---|
| 1. The Building Envelope (Outside wall and roof): | |
| Doors: Loose fitting | Weatherstripping |
| Do not close | Correct fit, check pressure |
| Windows: Air leakage | Weatherstrip, caulk |
| Broken | Replace panes |
| Walls: Cracks | Patch or seal |
| Roofs: Holes | Patch or cover |
| 2. Boiler and Steam Distribution: | |
| Boiler: Safety problems | Correct immediately |
| Inoperable gauges | Overhaul |
| Stack gas problem | Check and adjust |
| Scale deposits | Fix water treatment |
| Steam traps leak | Repair or replace |
| Steam leaks | Repair |
| Steam line insulation ragged or missing | Repair or replace |
| Condensate return system uninsulated but hot | Inslutate |

Table E.1 (Con't)

| System | Maintenance Activity |
| --- | --- |
| 3. Ventilation and Air Conditioning System: | |
| Filter very dirty | Replace or clean |
| Damper blocked or disconnected | Repair linkage and check controls |
| Ductwork blocked inside | Examine and repair |
| Grillwork blocked or dirty | Remove blockage, clean |
| Fan motor not connected | Replace belts or disconnect motor |
| Thermostat reading not accurate | Calibrate and correct |
| 4. Electrical System: | |
| Transformers: | |
| Leak | Replace immediately |
| Heat transfer surfaces fouled | Clean carefully |
| Contacts show burned spots | Repair immediately |
| Frayed wire | Tape carefully |
| Switch arc | Replace |
| 5. Lights, Windows and Reflective Surfaces: | |
| Unused space illuminated | Remove lights or install better switches |
| Ballasts buzz | Adjust |
| Lights flicker | Replace or illuminate |
| Windows and lamps dirty | Clean and paint |

Table E.1 (Con't)

| System | Maintenance Activity |
| --- | --- |
| 6. Air Compressors and Compressed Air Distribution System: | |
| Compressor air leaks | Overhaul |
| Compressor oil leaks | Overhaul |
| Oil in pneumatic control system | Overhaul compressor |
| Air line leaks | Repair |
| 7. Manufacturing System: | |
| Control not working | Overhaul |
| Working temperatures too high | Study and correct |
| Motor noisy | Check bearings |
| Motor hot | Adjust voltages on legs of three-phase input, correct belt tension |
| 8. Material Handling Systems: | |
| Excess use of diesel fuel | Follow manufacturer's recommended procedures |
| Uncontrol fuel use | Institute accounting of fuel per vehicle |
| Excessive tire wear | Check tire pressure |
| Excessive fuel use | Keep vehicles tuned up |

inch card for each piece of equipment, should include such information as bearing identification numbers; fan belt, chain and pulley numbers and vendors; motor serial and model numbers; and any other information that would be required when the machinery needed to be repaired or replaced.

During the facility inspections, careful note should be made of all suggestions received. These suggestions form the basis of the action phase. The products of the analysis are 1) a list of all equipment in each system, 2) a list of major repairs needed to bring each system into working condition, 3) a collection of maintenance manuals, assembled in one place, and 4) a set of cards with the information needed for routine maintenance on each piece of equipment.

In action phase, goals for maintenance are chosen, repair actions are prioritized, money is allocated, people are assigned to specific projects and a schedule for major repairs is agreed upon. These steps should be performed by a team that includes representatives from plant engineering, line management, the comptroller and anyone else who either is known to have good information or represents an interest group within the company.

Goals for energy maintenance can be defined in terms of specific repair actions being performed, the number of systems that have shifted from repair to preventive maintenance, and a reduction in energy costs directly attributable to maintenance. In the process of choosing goals, the team needs to decide how and when progress toward these goals is to be measured.

Once the team has established goals for the maintenance program, possible projects must be prioritized. Criteria for assigning priorities include the following: survivability of the company, safety, compliance with goverment regulations and project economics.

People and funds can now be assigned to the chosen projects. A schedule can be established for progress and for reporting each project. A list of particular maintenance tasks to be performed each day should also be prepared at this stage.

The last phase, monitoring, is to determine progress toward the goals established in the action phase. In the case of preventive maintenance, the schedule of daily maintenance tasks must be checked periodically. These schedule must be reviewed at least once a year to include any new equipment, to compare repair records with maintenance tasks and to determine if some of the routine maintenance should be eliminated or expanded.

The result of this final phase is closure-completion of the project by analyzing expected gains against real gains. The reasons for any discrepancy can then be used as the start of another analysis, action, monitoring cycle, and the process repeats.

APPENDIX F

# ENERGY AUDITS FOR THE CENTRAL AIR CONDITIONING SYSTEM

Table F.1 Energy Audit for the (Centrifugal Water Chiller) Air-Conditioning System (See Figure 6.1 thru 6.4 for More Details)

| Item | Equipment | Nameplate | | Actual | | | L.F. | P.F. | Hours |
|---|---|---|---|---|---|---|---|---|---|
| | | HP | A | kW | A | V | % | % | per Day |
| 1 | Cent. Water Chiller | 600 | 95 | 306$^{\pi}$ | 63 | - | - | - | All Equipment Run 24 Hours |
| 2 | Transformer | 2kVA | 6 | - | - | - | - | - | |
| 3 | Cooling Tower Fan-21 | 20 | 60 | 14.29 | 25.8 | 387 | 96 | 83 | |
| 4 | Cooling Tower Fan-22 | 20 | 60 | 14 | 32.9 | 387 | 94 | 87 | |
| 5 | Coondenser Pump-2 | 60 | 87 | 41.5 | 74.2 | 380 | 93 | 85 | |
| 6 | Cooling Tower Fan-1 | 25 | 58 | 3.15* | 10.1 | - | - | - | |
| 7 | Condenser Pump-11 | 55 | 73.9 | 37.5 | 64.5 | 385 | 91 | 87 | |
| 8 | Condenser Pump-12 | 55 | 73.9 | 41.2 | 70.6 | 382 | 100.4 | 88 | |
| 9 | Chilled Water Pump-1 | 40 | 61 | 28.4 | 49.8 | 385 | 95 | 86 | |
| 10 | CHPF | 5 | 8.5 | 2.73* | 5 | - | - | - | |
| 11 | Hot Well Pump | 15 | 22.5 | 8.4 | 15.1 | 383 | 75 | 84 | |
| 12 | Quench Air Fan | 60 | 82 | 34.3* | 62.7 | - | - | - | |
| 13 | Spinning AWSR Pump-1 | 15 | 23.6 | 8.06 | 15.83 | 383 | 72 | 77 | |
| 14 | Spinning AWSR Pump-2 | 15 | 23.6 | 8.06 | 15.83 | 383 | 72 | 77 | |
| 15 | Fan Coil Unit Blower | 10 | 15 | 6.14 | 13.5 | 384 | 82 | 68 | |
| 16 | Draw-Twist. AWSR Fan | 125 | 187 | 38.2* | 70 | - | - | - | |
| 17 | Draw-Twist. AWSR Pump | 40 | 60 | 20.2 | 36.8 | 385 | 68 | 82 | |
| | Total | 1200 | - | 612.13 | | | 938.4 | 904 | |
| | Average | | | | | | 85.3 | 82.2 | |

Remark: Each of item 1,2,5,9, and 11 possesses one standby.

$\pi$ This yalue is estimated based on PF = 0.85 and vottage of 3.3 kV.

* This value is estimated based on PF = 0.83 and voltage = 380 V.

Table F.2 Energy Audit for the (Brine chiller) Air-Conditioning System

(See Figure 6.5 and 6.6 for More Details)

| Item | Equipment | Nameplate | | Actual | | | L.F. | P.F. | Hours per Day |
|---|---|---|---|---|---|---|---|---|---|
| | | HP | A | KW | A | V | % | % | |
| 1 | Recip. Brine Chiller | 75 | 104 | 32.3 | 57.4 | 374 | 58 | 87 | All Equipment Run 24 Hours |
| 2 | Recip. Brine Chiller | 100 | 143 | 44.7 | 102.2 | 383 | 60 | 66 | |
| 3 | Cooling Tower Fan-1 | 5 | 7.5 | 1.0* | 3.1 | - | - | - | |
| 4 | Cooling Tower Fan-2 | 5 | 7.5 | 1.32* | 4.2 | - | - | - | |
| 5 | Condenser Pump | 40 | 60 | 28.5 | 50.1 | 383 | 96 | 86 | |
| 6 | Cooling Water Pump-1 | 3 | 3.5 | 1.13* | 3.5 | - | - | - | |
| 7 | Cooling Water Pump-2 | 2 | 3 | 0.969* | 3 | - | - | - | |
| 8 | Chilled Water Pump | 10 | 15.8 | 7.59 | 13.52 | 382 | 101.7 | 85 | |
| 9 | Cooling Air Fan | 25 | 37.5 | 9.69* | 30 | - | - | - | |
| | Total | 265 | | 127.2 | | | | | |

Remark: Each of item 1, 5, and 8 possesses one standby.

* This entry is estimated based on PF = 0.85 and voltage = 380 V.

Table F.3 Energy Audit for the Office Air Conditioning System

(See Figure 6.7 for More Details)

| Item | Equipment | Nameplate | | Actual | | | L.F. | P.F. | Hours per Day |
|---|---|---|---|---|---|---|---|---|---|
| | | HP | A | kW | A | V | % | % | |
| 1 | Recip.Water Chiller | 40 | 61 | 19.57 | 40.4 | 380 | 66 | 74 | Run 9 Hours |
| 2 | Chilled Water Pump | 7 | 12.2 | 5.22 | 12.2 | - | 100 | - | |
| 3 | Condenser Pump | 5 | 8.5 | 3.73 | 9.3 | - | 100 | - | |
| 4 | Cooling Tower Fan | 3 | 4.5 | 2.34 | 4.5 | - | 100 | - | |
| | Total | | | 30.86 | | | | | |

APPENDIX G

DETAILED CALCULATIONS FOR THE ANALYSIS OF AIR CONDITIONING SYSTEM

## G.1 Calculations for the Analysis of the Draw-Twisting Building

The draw-twisting building is located within the manufacturing building group (see Appendix A) with the structure as illustrated in Figure 6.10. The process within this building space requires air-conditioning maintained at about 24°C (75.2°F) DB and 20°C (68°F) WB which is corresponding to the relative humidity of 70% (see Figure G.1 and Figure G.2).

Reduction of heat gain to the building space can be considered as follows:

1. Reduction of heat gain through the roof after installation of fiberglass.

2. Reduction of heat gain from the wall above this insulated ceiling.

### 1. Reduction of Heat Gain Through the Roof

The coefficient of transmission, U, before installation of the ceiling can be computed as follows:

1. Outside air film (15 mph wind), $R_1$ = 0.17.
2. Precast cement tile, $R_2$ = 1.30.
3. 4"thick concrete, metal lath and plaster ceiling, $R_3$ = 2.50.
4. Inside air film (still air), $R_4$ = 0.68.

Total thermal resistance, $R_{T1}$ = 4.6 or $U_1$ = 0.215 Btu/(hr. $ft^2$ °F).

The U-value after installation of the ceiling can be computed as follows:

1. The existing thermal resistance, $R_{T1}$ = 4.6.
2. 25 mm. thickness fiberglass, $R_5$ = 4.3.*

Total thermal resistance after this proposal, $R_{T2}$ = 8.9 or $U_2$ = 0.112 Btu/(hr. $ft^2$ °F).

It is noted that the U-valve is reduced by 0.103 Btu/(hr. $ft^2$ °F).

The amount of heat gain through the roof is calculated by

$$Q = U.A.\, \Delta T_{eq}$$

where $Q$ = the amount of heat gain, Btu per hour;

$U$ = coefficient of transmission, Btu/(hr. $ft^2$ °F);

$A$ = roofing surface area, 29600 sq. ft;

$\Delta T_{eq}$ = equivalent temperature difference (°F), as given in Table G.1.

Computations for the heat gain using the data described above are summarized in Table G.1. The reduction in heat gain after installing this insulated ceiling is the sum of $Q_1$ (=3,487,471 Btu/day) minus the sum of $Q_2$ (=1,816,729 Btu/day) which equals 1,670,742 Btu/day.

2. <u>Reduction of Heat Gain from the Wall above the Insulated Ceiling.</u>

The building under consideration is composed of four (4) sides of brick walls

The west wall is a boundary that separates the draw-twisting space from the take-up core storage room. Since the conditions of this

---

*The value is provided by the manufacturer of this material.

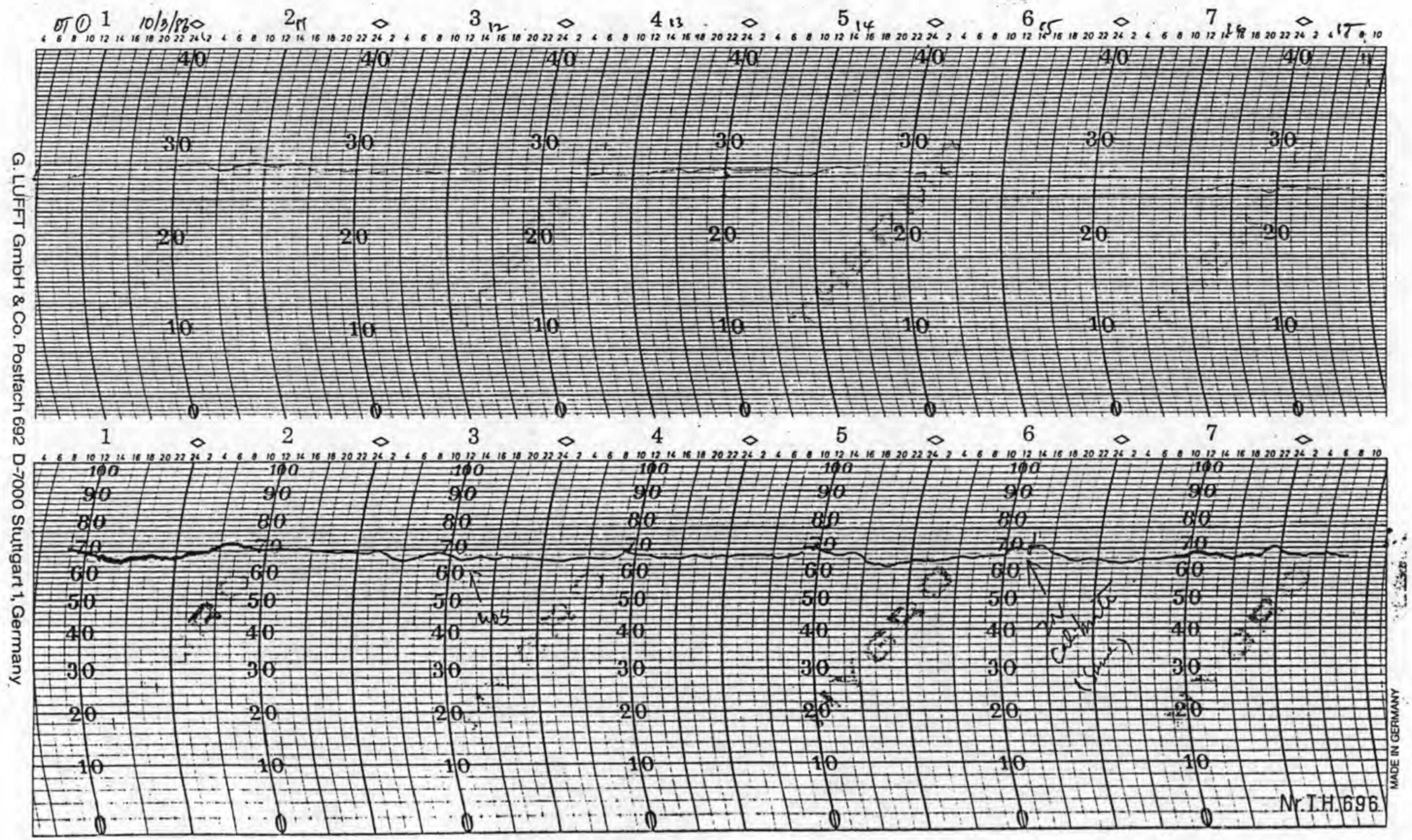



Figure G.1 Control Chart for Temperature and Relative Humidity of the Draw-Twisting Space

Figure G.2

# PSYCHROMETRIC CHART

**Normal Temperatures**

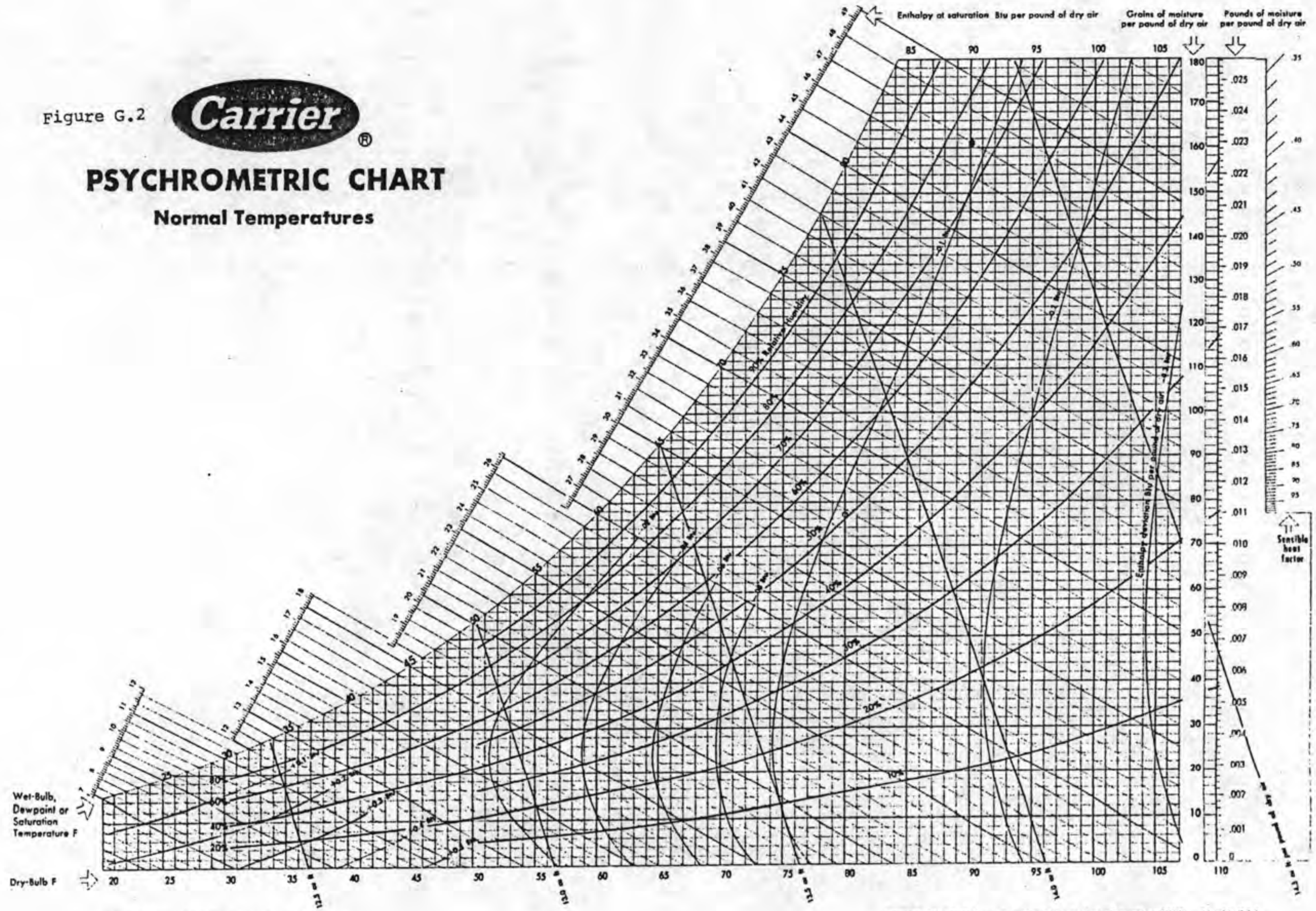


Table G.1 Calculations for Heat Gain Through the Roof of the Draw-Twisting Building

| Item | SUN TIME | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AM | | | | | | | PM | | | | | | | | | | | | AM | | | | |
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 |
| $\Delta T_{eq}$ | 4 | 3 | 2 | 4 | 6 | 13 | 20 | 28 | 35 | 41 | 46 | 49 | 49 | 46 | 40 | 35 | 30 | 25 | 20 | 16 | 12 | 10 | 8 | 6 |
| $Q_1$ | 25456 | 19092 | 12728 | 25456 | 38184 | 82732 | 127280 | 178192 | 222740 | 260924 | 292744 | 311836 | 311836 | 292744 | 254560 | 222740 | 190920 | 159100 | 127280 | 101824 | 76368 | 63640 | 50912 | 38184 |
| $Q_2$ | 13261 | 9946 | 6630 | 13261 | 19891 | 43098 | 66304 | 92826 | 116032 | 135923 | 152499 | 162445 | 162445 | 152499 | 132608 | 116032 | 99456 | 82880 | 66304 | 53043 | 39782 | 33152 | 26522 | 19891 |
| $(Q_1-Q_2)$ | 12195 | 9146 | 6098 | 12195 | 18293 | 39634 | 60976 | 85366 | 106708 | 125001 | 140245 | 149391 | 149391 | 140245 | 121952 | 106708 | 91464 | 76220 | 60976 | 48781 | 36586 | 30488 | 24390 | 18293 |

Remarks: 1. Heat Gain thru the Roof (Q), Btu/hr = U.A $\Delta T_{eq}$, $Q_1$ = without insulation and $Q_2$ = with insulation.

2. The roof is assumed to have the weight of 20 lb/sq ft with the condition of "Exposed to the Sun."

3. The values of equivalent temperature difference (°F), $\Delta T_{eq}$, is developed for April & 14°N Latitude (24) which is applicable to Samutsakorn province.

4. $Q_1 = (0.215)(29600)(\Delta T_{eq})$ and $Q_2 = (0.112)(29600)(\Delta T_{eq})$

Source: $\Delta T_{eq}$ values are taken from a lecture note on air conditioning design (24). see Table G.6.

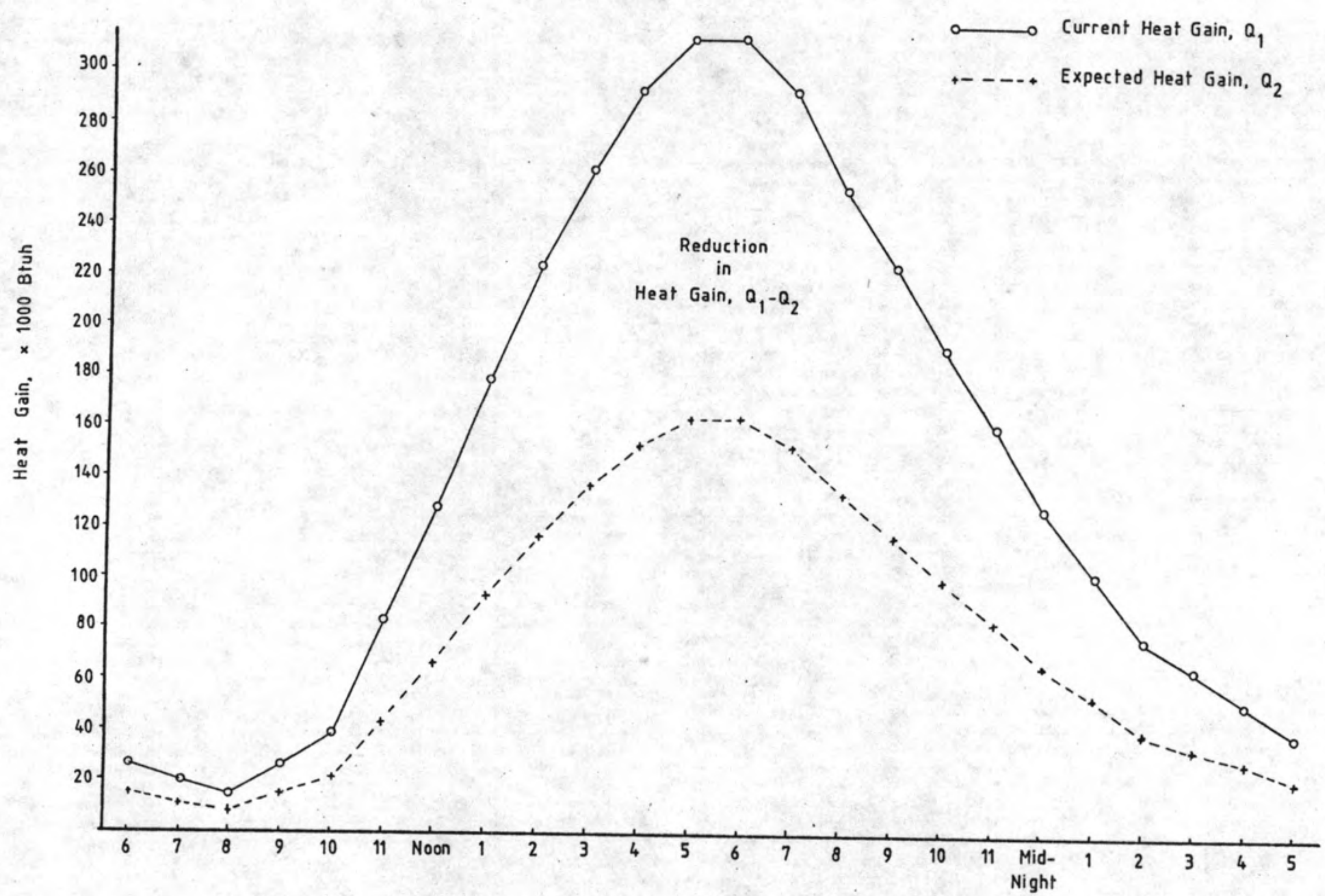


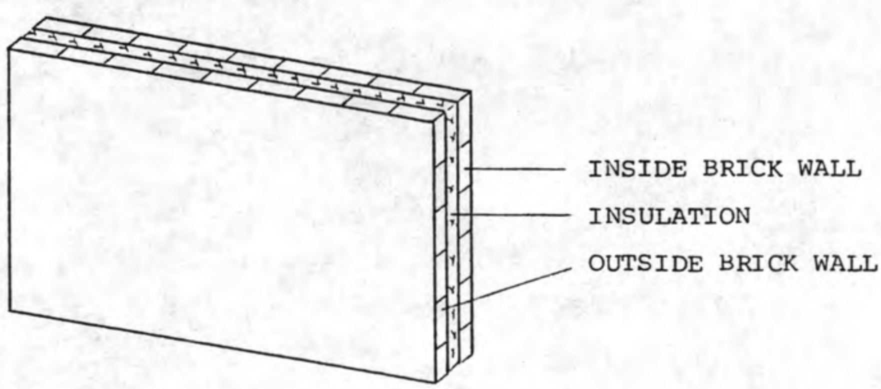

Figure G.3 Plot of Heat Gain Through the Roof of the Draw-Twisting Building (See Table G.1) two areas are almost the same, heat transfer through this wall is assumed to be zero.

The east wall is a common wall of the shipping warehouse and the draw-twisting building. This warehouse is a non-air-Conditioned space with the condition nearly the same as those of outside space. The wall area above the proposed ceiling is 100 square meters (50 m x 2m) or 1076 sq ft.

The north and south walls are exposed to outside space with the wall area above the ceiling of 110 square meters (55 m x 2m) or 1184 sq ft each.

Generally, shaded walls and north exposures have the same equivalent temperature difference (13). Hence, the north and east walls in this calculation are considered as a unique wall with the area of 2260 sq ft (1076 sq ft of the east wall plus 1184 sq ft of the north side.)

The existing walls are of double bricks with stramit board (insulation) inside. The transmission coefficient, U, in Btu per (hour)(sq ft)(deg F) can be computed as follows:



1. Outside air film (15 mph wind) $R_1$ = 0.17.
2. Double common brick, 8 in, k=5; $R_2$ = 1.60.
3. Stramit board (insulation) $R_3$ = 1.25.
4. Inside air film (still air) $R_4$ = 0.68.

Total thermal resistance, $R_T$ = 3.7.

Therefore, the U-value of these walls is 0.27 ($U = 1/R_T$).

The calculations for heat gain through walls are illustrated in Table G.2. To attain the total heat gain, we proceed as follows:

Heat gain thru the north and east (shade) walls is the sum of $Q_{ns}$ in Table G.2 throughout the day (24 hours) = 104344 Btu/day.

Heat gain thru the south wall is the sum of $Q_s$ in Table Q.2 throughout the day (24 hours) = 91,429 Btu/day.

Hence, the total heat gain is 104,344 + 91,429 = 195,773 Btu/day.

After installation of the fiberglass ceiling, this wall area (above the ceiling) is considered as a component the roof. Therefore, the amount of heat gain of 195,773 Btu/day is blocked by the proposed ceiling.

According to the calculations given above, the total reduction of heat gain is the sum of heat gain through the roof reduced (1,670,742 Btu/day) and that amount blocked by the ceiling (195,773 Btu/day) which equals 1,866,515 Btu/day.

Table G.2 Calculations for Heat Gain Through Walls above the Proposed Ceiling

| Item | SUN TIME | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AM | | | | | | | PM | | | | | | | | | | | | AM | | | | |
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 |
| $\Delta T_{eq}$ (North Shade) | 0.5 | 0.5 | -0.5 | -0.5 | 1.5 | 2.5 | 3.5 | 9.5 | 9.5 | 11.5 | 13.5 | 14.5 | 15.5 | 15.5 | 15.5 | 12.5 | 11.5 | 9.5 | 7.5 | 5.5 | 4.5 | 3.5 | 2.5 | 1.5 |
| $Q_{ns}$ | 305 | 305 | -305 | -305 | 915 | 1526 | 2136 | 5797 | 5797 | 7017 | 8238 | 8848 | 9458 | 9458 | 9458 | 7628 | 7017 | 5797 | 4577 | 3356 | 2746 | 2136 | 1526 | 915 |
| $\Delta T_{eq}$ (South) | 2.5 | 0.5 | -0.5 | 0.5 | 1.5 | 10.5 | 15.5 | 23.5 | 27.5 | 28.5 | 29.5 | 26.5 | 23.5 | 18.5 | 15.5 | 13.5 | 11.5 | 9.5 | 7.5 | 5.5 | 4.5 | 4.5 | 3.5 | 2.5 |
| $Q_{so}$ | 799 | 160 | -160 | 160 | 480 | 3357 | 4955 | 7512 | 8791 | 9111 | 9431 | 8472 | 7512 | 5914 | 4955 | 4316 | 3676 | 3037 | 2398 | 1758 | 1439 | 1439 | 1119 | 799 |

Remarks: 1. Heat Gain Through Walls (Q), Btu/hr = U.A. $\Delta T_{eq}$, $Q_{ns}$ = thru north and east (shaded) walls, and $Q_s$ = thru south wall.

2. The walls are assumed to be of 60 lb/sq ft.

3. The values of equivalent temperature difference (°F), $\Delta T_{eq}$, is developed for April & 14°N Latitude (24) which is applicable to Samutsakorn province.

4. $Q_{ns} = (0.27)(2260)\ (\Delta T_{eq}\binom{North}{Shade})$ and $Q_{so} = (0.27)(1184)\ \Delta T_{eq}(South)$

Source: $\Delta T_{eq}$ values are taken from a lecture note on air conditioning design (24). see Table G.7.

Table G.3 Outdoor Conditions for the Peak Month (April)

| Item | SUN TIME | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AM | | | | | | | PM | | | | | | | | | | | | AM | | | | |
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 |
| DB Temp (°F) | 78.0 | 78.7 | 79.9 | 82.7 | 85.0 | 88.8 | 90.9 | 92.5 | 93.5 | 93.9 | 93.7 | 93.0 | 91.3 | 89.4 | 87.3 | 85.4 | 83.6 | 82.9 | 81.4 | 80.2 | 79.5 | 79.0 | 78.6 | 78.3 |
| WB Temp (°F) | 76.0 | 76.5 | 76.9 | 78.8 | 79.9 | 80.8 | 81.2 | 82.0 | 82.0 | 82.1 | 81.6 | 81.1 | 80.6 | 80.2 | 79.5 | 78.9 | 78.5 | 78.5 | 77.6 | 77.2 | 77.0 | 76.8 | 76.7 | 76.7 |
| Enthalpy (Btu/lb of dry air) | 39.6 | 40.1 | 40.5 | 42.5 | 43.6 | 44.5 | 45.0 | 45.9 | 45.9 | 46.0 | 45.4 | 44.9 | 44.3 | 43.9 | 43.1 | 42.5 | 42.1 | 42.1 | 41.2 | 40.8 | 40.6 | 40.4 | 40.3 | 40.3 |

Remarks: 1. The temperatures, db and wb, are provided by the Grim Carrier Co., Ltd.

2. The values of enthalpy are found from the Psychrometric Chart (Copyright 1947 Carrier Corporation-Copyright 1959 Carrier Corporation-AC 467), see Figure G.2.

3. The average enthalpy = 42.729 Btu per pound of dry air.

Source: Temperatures are generated by a Carrier Computer Package.

Table G.4 Cooling Load Estimation for the office Rooms

SHEET ____ DATE ____
PREPARED BY ____
NAME OF JOB ____
LOCATION SAMUTSAKORN PROVINCE

OFFICE 3 P.M.
PROP NO. ____ JOB NO. ____
APPROVED ____

SPACE USED FOR MANAGEMENT & PAPERWORK
SIZE 49.2 x 82.02 4037 SQ FT x 9.84 . 39724 CU FT

| ITEM | AREA OR QUANTITY | SUN GAIN OR TEMP. DIFF. | FACTOR | BTU/HOUR |
|---|---|---|---|---|
| **SOLAR GAIN – GLASS** | | | | |
| GLASS E(1) | 65 SQ FT x | 13F | x .65 | 549 |
| GLASS E(2) | 97 SQ FT x | 13F | x .65 | 820 |
| GLASS W(1) | 200 SQ FT x | 149F | x .65 | 19370 |
| GLASS W(2) | 87 SQ FT x | 149F | x .65 | 8426 |
| SKYLIGHT | – SQ FT x | – | x – | – |
| **SOLAR & TRANS. GAIN – WALLS & ROOF** | | | | |
| WALL E(1+2) | 647 SQ FT x | 16.5F | x .46 | 4911 |
| WALL W(1+2) | 560 SQ FT x | 35.5F | x .46 | 9145 |
| WALL N(1+2) | 970 SQ FT x | 15.5F | x .46 | 6916 |
| WALL S(1+2) | 728 SQ FT x | 31.5F | x .46 | 10549 |
| ROOF – SUN | – SQ FT x | – | x – | – |
| ROOF – SHADED | – SQ FT x | – | x – | – |
| **TRANS. GAIN – EXCEPT WALLS & ROOF** | | | | |
| ALL GLASS | 692 SQ FT x | 17F | x 1.0 | 11764 |
| PARTITION | – SQ FT x | – | x – | – |
| CEILING | 4037 SQ FT x | 17F | x .3 | 20589 |
| FLOOR | – SQ FT x | – | x – | – |
| INFILTRATION | 1100 CFM x | 17F | x 1.09 | 20383 |
| **INTERNAL HEAT** | | | | |
| PEOPLE | 19 | | x 215 | 4085 |
| POWER | – | HP OR KW x | – | – |
| LIGHTS | 2225 | WATTS x | 1.25x3.4 | 9456 |
| APPLIANCES, ETC. | (XEROX) 1500 W | | x 3.4 | 5100 |
| ADDITIONAL HEAT GAINS | – | | x – | – |
| | | | SUB TOTAL | 132063 |
| STORAGE | – SQ FT x | – | x (– ) | – |
| | | | SUB TOTAL | – |
| SAFETY FACTOR | 2 | | % | 2641 |
| | | | ROOM SENSIBLE HEAT (RSH) = | 134704 |
| SUPPLY DUCT HEAT GAIN 4 % + SUPPLY DUCT LEAK LOSS 2 % + FAN H.P. 4 % | | | | 13470 |
| OUTDOOR AIR | 605 CFM x | 17 F x | .05 BF x 1.09 | 561 |
| | | | EFFECTIVE ROOM SENSIBLE HEAT (ERSH) = | 148735 |
| **LATENT HEAT** | | | | |
| INFILTRATION | 1100 CFM x | 82 | GR/LB x 0.68 | 61336 |
| PEOPLE | 19 | | x 235 | 4465 |
| STEAM | – | LB/HR x 1050 | – | – |
| APPLIANCES, ETC. | – | | | – |
| ADDITIONAL HEAT GAINS | – | | | – |
| VAPOR TRANS | – SQ FT x 1/100 x | – GR/LB x | – | – |
| | | | SUB TOTAL | 65801 |
| SAFETY FACTOR | 2 | | % | 1316 |
| | | | ROOM LATENT HEAT (RLH) | 67117 |
| SUPPLY DUCT LEAKAGE LOSS | 2 | | % | 1342 |
| OUTDOOR AIR | 605 CFM x | 82 GR/LB | .82 BF x 0.68 | 1687 |
| | | | EFFECTIVE ROOM LATENT HEAT (ERLH) | 70146 |
| | | | EFFECTIVE ROOM TOTAL HEAT (ERTH) = | 218881 |
| **OUTDOOR AIR HEAT** | | | | |
| SENSIBLE | 605 CFM x | 17 F x (1 – | .05 BF) x 1.09 | 10650 |
| LATENT | 605 CFM x | 82 GR/LB x (1 – | .05 BF) x 0.68 | 32048 |
| RETURN DUCT HEAT GAIN %RSH + RETURN DUCT LEAKAGE GAIN %RSH | | | | – |
| RETURN AIR OR BLOW THRU FAN | 1.0 | | H.P. x 2545 | 2545 |
| | | | GRAND TOTAL HEAT (GTH) OR DEHUMIDIFIER LOAD = | 264124 |
| PUMP H.P. %GTH + PIPING HEAT GAIN %GTH | | | | |
| | | | REFRIGERATION LOAD = | 22 TR |

| ESTIMATE FOR | LOCAL TIME SUN TIME | PEAK LOAD | LOCAL TIME SUN TIME |
|---|---|---|---|
| EQUIPMENT OPERATION | 9 | HOURS/DAY | |

| CONDITIONS | DB | WB | %RH | DP | GR/LB |
|---|---|---|---|---|---|
| OUTDOOR (OA) | 95 | 78 | 61 | 79.5 | 153 |
| ROOM (RM) | 78 | 65 | 50 | 58 | 71 |
| DIFFERENCE | 17 | XXX | XXX | XXX | 82 |

**OUTDOOR AIR**

Ventilation: 19 PEOPLE x 10 CFM/PERSON = 190; 4037 SQ FT x .15 CFM/SQ FT = 605; CFM VENTILATION = 605

Infiltration: SWINGING, REVOLVING DOORS ____ PEOPLE x ____ CFM/PERSON = ____; OPEN DOORS ____ DOORS x ____ CFM/DOOR = ____; EXHAUST FAN ____; CRACK ____ FEET x ____ CFM/FT = ____; CFM INFILTRATION = SEE NOTES

CFM OUTDOOR AIR THRU APPARATUS = ____ $CFM_{OA}$

**APPARATUS DEWPOINT & DEHUMIDIFIED AIR QUANTITY**

ESHF: EFFECTIVE SENSIBLE HEAT FACTOR = 148735 / 218881 = ERSH / ERTH = 0.68

ADP: INDICATED ADP = ____ F SELECTED ADP = ____ F

Dehum. Rise: (1 – ____ BF) x ($T_{RM}$ ____ F – $T_{ADP}$ ____ F) = ____ F

Dehum. Cfm: ERSH / (1.09 x $F_{DEHUM. RISE}$) = ____ $CFM_{DA}$

**SUPPLY AIR QUANTITY**

Outlet Temp. Diff.: RSH / (1.09 x $CFM_{DA}$) = ____ F (RM – OUTLET AIR)*

Supply Cfm: RSH / (1.09 x $F_{DESIRED DIFF.}$) = ____ $CFM_{SA}$

Bypass Cfm: ____ $CFM_{SA}$ – ____ $CFM_{DA}$ = ____ $CFM_{BA}$

*IF THIS AT IS TOO HIGH, DETERMINE SUPPLY CFM FOR DESIRED DIFFERENCE BY SUPPLY AIR QUANTITY FORMULA.

**RESULTING ENT & LVG CONDITIONS AT APPARATUS**

$T_{RM}$ ____ F + ($CFM_{OA}$ / CFM) x ($T_{OA}$ ____ F – $T_{RM}$ ____ F) = $T_{EDB}$ ____ F

$T_{ADP}$ ____ F + ____ BF x ($T_{EDB}$ ____ F – $T_{ADP}$ ____ F) = $T_{LDB}$ ____ F

FROM PSYCH CHART: $T_{EWB}$ ____ F, $T_{LWB}$ ____ F

WHEN BYPASSING A MIXTURE OF OUTDOOR AND RETURN AIR, USE SUPPLY CFM. WHEN BYPASSING RETURN AIR ONLY, USE DEHUMIDIFIED CFM.

**NOTES**

INFILTRATION = (HxLxWxG)/60

= 39724 x 1.5 / 60

= 993.4 USE 1000 CFM

DOOR INFILTRATION = (DOOR OPENING/HR) x100 / 60

DOOR OPENING = 2 TIMES/PERSON/HR

∴ TOTAL INFILTRATION = 1100 CFM

E-20 (5-77) (905–013)

Table G.5 SOLAR HEAT GAIN THRU ORDINARY GLASS Btu/(hr)(sq ft sash area)

13.8°N LAT

| NORTH LATITUDE | | AM | | | | | | SUN TIME | | | | PM | | | SOUTH LATITUDE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time of Year | Exposure | 6 | 7 | 8 | 9 | 10 | 11 | Noon | 1 | 2 | 3 | 4 | 5 | 6 | Exposure | Time of Year |
| | North | 3 | 13 | 14 | 14 | 15 | 14 | 14 | 14 | 15 | 14 | 14 | 13 | 3 | South | |
| | Northeast | 28 | 112 | 125 | 102 | 68 | 28 | 14 | 14 | 14 | 13 | 11 | 7 | 1 | Southeast | |
| | East | 36 | 140 | 164 | 149 | 105 | 48 | 14 | 14 | 14 | 13 | 11 | 7 | 1 | East | |
| Aug. 24 | Southeast | 22 | 83 | 102 | 94 | 75 | 38 | 16 | 14 | 14 | 13 | 11 | 7 | 1 | Northeast | Feb. 20 |
| & | South | 1 | 7 | 11 | 13 | 16 | 18 | 19 | 18 | 16 | 13 | 11 | 7 | 1 | North | & |
| Apr. 20 | Southwest | 1 | 7 | 11 | 13 | 14 | 14 | 16 | 38 | 75 | 94 | 102 | 83 | 22 | Northwest | Oct. 23 |
| | West | 1 | 7 | 11 | 13 | 14 | 14 | 14 | 48 | 90 | 149 | 164 | 140 | 36 | West | |
| | Northwest | 1 | 7 | 11 | 13 | 14 | 14 | 14 | 28 | 29 | 102 | 125 | 112 | 28 | Southwest | |
| | Horizontal | 3 | 42 | 106 | 167 | 212 | 235 | 249 | 239 | 212 | 167 | 106 | 42 | 3 | Horizontal | |

| Solar correction gain | steel Sash, or No Sash x 1/.85 or 1.17 | Haze - 15% (Max) | Altitude +0.7% per 1000 Ft. | Dew point Decrease from 67°F + 7% per 10°F | Dew point Increase from 67°F - 7% per 10°F |
|---|---|---|---|---|---|

Source: A lecture note on air conditioning design (24)

Table G.6 Equivalent Temp Difference (°F) Dark Colored Sunlit & Shaded Roof.

Correction already made for: Outdoor, Indoor temp, Daily range. This table then based on Dark colored wall, 95 °F db. Outdoor Design Temp. Constant 73 °F db room temp. 17 °F Daily range 24 hr. operation, April & 13.8°N Lat.

| CONDITION | WEIGHT OF ROOF (lb/Sq.ft) | SUN TIME | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AM | | | | | | | PM | | | | | | | | | | | | | AM | | | | |
| | | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 |
| Exposed to Sun | 10 | -4 | -3 | -4 | -2 | 2 | 10 | 19 | 23 | 37 | 43 | 48 | 52 | 49 | 47 | 41 | 32 | 27 | 21 | 14 | 11 | 7 | 5 | 3 | 2 |
| | 20 | 4 | 3 | 2 | 4 | 6 | 13 | 20 | 28 | 35 | 41 | 46 | 49 | 49 | 46 | 40 | 35 | 30 | 25 | 20 | 16 | 12 | 10 | 8 | 6 |
| | 40 | 8 | 7 | 6 | 7 | 10 | 14 | 21 | 28 | 33 | 38 | 43 | 45 | 47 | 45 | 40 | 37 | 33 | 29 | 25 | 22 | 16 | 16 | 13 | 19 |
| | 60 | 13 | 12 | 10 | 11 | 12 | 15 | 21 | 27 | 32 | 36 | 40 | 44 | 45 | 44 | 41 | 39 | 36 | 33 | 30 | 27 | 28 | 21 | 18 | 15 |
| | 80 | 18 | 17 | 15 | 15 | 17 | 18 | 21 | 27 | 31 | 33 | 37 | 40 | 43 | 42 | 40 | 36 | 39 | 37 | 35 | 32 | 28 | 25 | 23 | 19 |
| Covered with water | 20 | -2 | 2 | 4 | 6 | 8 | 14 | 20 | 23 | 26 | 24 | 22 | 20 | 18 | 16 | 14 | 10 | 6 | 5 | 5 | 3 | 2 | 1 | .4 | -2 |
| | 40 | 1 | 2 | 3 | 3 | 4 | 9 | 14 | 13 | 19 | 19 | 20 | 19 | 19 | 18 | 16 | 14 | 11 | 9 | 7 | 5 | 3 | 2 | 1 | 1 |
| | 60 | 3 | 2 | 2 | 2 | 2 | 6 | 9 | 14 | 18 | 20 | 22 | 23 | 23 | 22 | 20 | 18 | 16 | 14 | 12 | 10 | 8 | 7 | 6 | 5 |
| Sprayed | 20 | -4 | 2 | 4 | 6 | 8 | 12 | 16 | 19 | 22 | 21 | 20 | 19 | 18 | 16 | 14 | 10 | 6 | 5 | 4 | 3 | 2 | 2 | 1 | 1 |
| | 40 | 2 | 2 | 3 | 3 | 4 | 6 | 9 | 13 | 17 | 18 | 18 | 18 | 18 | 17 | 16 | 18 | 12 | 9 | 7 | 5 | 4 | 4 | 3 | 3 |
| | 60 | 3 | 2 | 2 | 2 | 2 | 4 | 6 | 9 | 12 | 14 | 16 | 17 | 18 | 17 | 16 | 15 | 14 | 12 | 10 | 8 | 6 | 5 | 4 | 3 |
| Shaded | 20 | -2 | -2 | -1 | 2 | 4 | 6 | 10 | 13 | 16 | 17 | 18 | 17 | 16 | 14 | 12 | 9 | 6 | 5 | 4 | 3 | 1 | -1 | -2 | -2 |
| | 40 | -2 | -2 | -1 | 1 | 2 | 4 | 6 | 9 | 12 | 14 | 16 | 17 | 16 | 15 | 14 | 12 | 10 | 8 | 6 | 4 | 3 | 1 | -1 | -2 |
| | 60 | 1 | 1 | 2 | 2 | 2 | 3 | 4 | 6 | 8 | 10 | 12 | 13 | 14 | 14 | 14 | 13 | 12 | 10 | 8 | 6 | 5 | 4 | 3 | 2 |
| | | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 |
| | | AM | | | | | | | PM | | | | | | | | | | | | AM | | | | |
| | | SUN TIME | | | | | | | | | | | | | | | | | | | | | | | |

Source: A lecture note on air conditioning design (24)

Table G.7 Equivalent Temp Difference °F, Dark Colored Sunlit & Shaded Wall

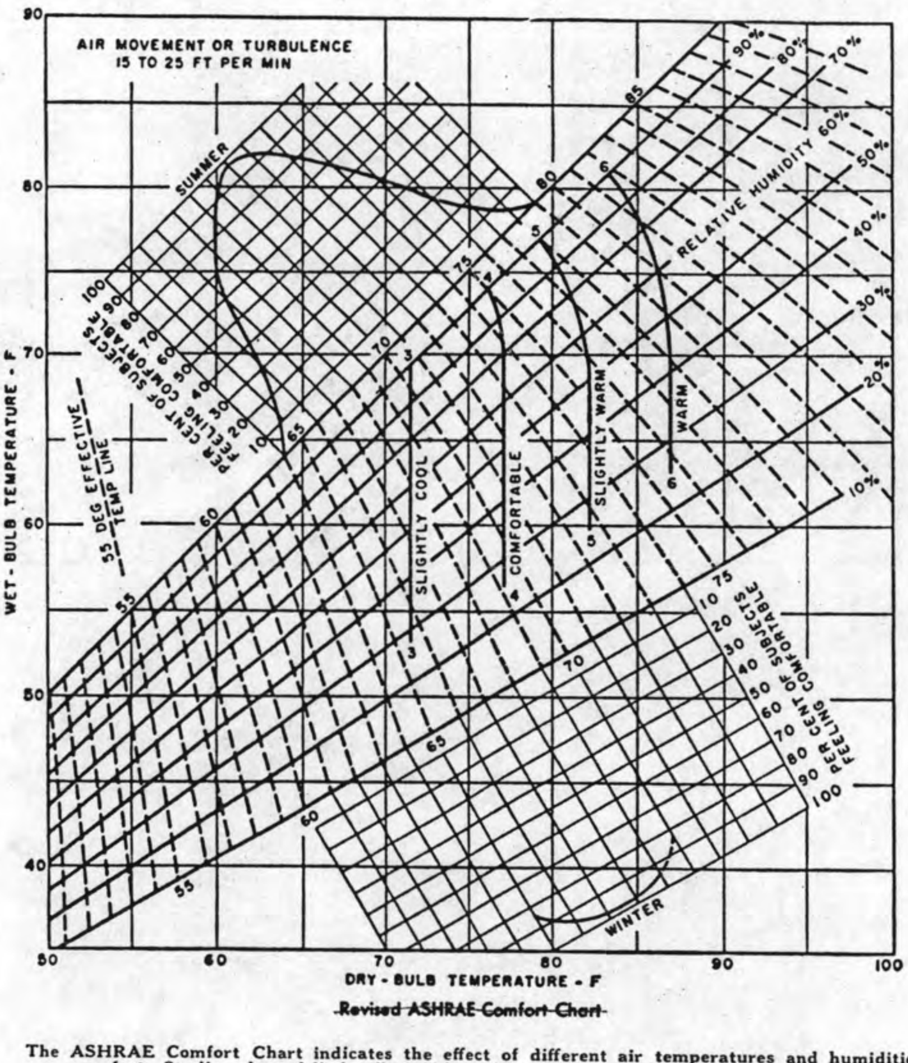
Correction already made for outdoor, indoor temp, daily range. This table then based on dark colored wall, 95 °F db outdoor design temp, constant 78 °F db room temp, 17 °F daily range 24 hr operation, April 13.8 °N Lat.

| EXPOSURE | WEIGHT OF WALL (lb/sq.ft) | SUNTIME AM 6 | AM 7 | AM 8 | AM 9 | AM 10 | AM 11 | AM 12 | PM 1 | PM 2 | PM 3 | PM 4 | PM 5 | PM 6 | PM 7 | PM 8 | PM 9 | PM 10 | PM 11 | AM 12 | AM 1 | AM 2 | AM 3 | AM 4 | AM 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Northeast | 20 | 8.5 | 13.5 | 25.5 | 26.0 | 27.5 | 22.5 | 17.5 | 18.5 | 19.5 | 16.5 | 17.5 | 17.5 | 17.5 | 15.5 | 13.5 | 11.5 | 9.5 | 7.5 | 5.5 | 3.5 | 1.5 | 0.5 | 0.5 | 1.5 |
| | 60 | 2.5 | 11.5 | 1.5 | 3.5 | 27.5 | 25.5 | 23.5 | 18.5 | 13.5 | 14.5 | 15.5 | 16.5 | 17.5 | 16.5 | 15.5 | 14.5 | 13.5 | 11.5 | 9.5 | 7.5 | 5.5 | 4.5 | 3.5 | 2.5 |
| | 100 | 7.5 | 6.5 | 7.5 | 7.5 | 7.5 | 13.5 | 19.5 | 18.5 | 17.5 | 15.5 | 13.5 | 14.5 | 15.5 | 15.5 | 15.5 | 14.5 | 13.5 | 12.5 | 11.5 | 10.5 | 9.5 | 9.5 | 8.5 | 8.5 |
| | 140 | 8.5 | 8.5 | 9.5 | 9.5 | 9.5 | 9.5 | 9.5 | 13.5 | 17.5 | 19.5 | 17.5 | 15.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 12.5 | 12.5 | 11.5 | 10.5 | 10.5 |
| East | 20 | 4.5 | 20.5 | 30.5 | 37.5 | 39.5 | 38.5 | 36.5 | 23.5 | 15.5 | 16.5 | 18.5 | 17.5 | 17.5 | 15.5 | 13.5 | 11.5 | 9.5 | 7.5 | 5.5 | 3.5 | 2.5 | 1.5 | 0.5 | 0.5 |
| | 60 | 2.5 | 2.5 | 3.5 | 24.5 | 23.5 | 34.5 | 34.5 | 22.5 | 27.5 | 13.5 | 15.5 | 16.5 | 17.5 | 16.5 | 15.5 | 11.5 | 13.5 | 11.5 | 8.5 | 7.5 | 6.5 | 4.5 | 4.5 | 3.5 |
| | 100 | 8.5 | 8.5 | 9.5 | 11.5 | 17.5 | 23.5 | 27.5 | 23.5 | 27.5 | 23.5 | 21.5 | 19.5 | 17.5 | 17.5 | 17.5 | 16.5 | 15.5 | 14.5 | 13.5 | 12.5 | 11.5 | 10.5 | 10.5 | 9.5 |
| | 140 | 14.5 | 13.5 | 13.5 | 12.5 | 11.5 | 12.5 | 13.5 | 18.5 | 21.5 | 22.5 | 21.5 | 20.5 | 19.5 | 17.5 | 15.5 | 16.5 | 17.5 | 17.5 | 17.5 | 14.5 | 16.5 | 15.5 | 15.5 | 15.5 |
| Southeast | 20 | 13.5 | 9.5 | 16.5 | 22.5 | 23.5 | 20.5 | 31.5 | 29.5 | 27.5 | 22.5 | 13.5 | 18.5 | 17.5 | 15.5 | 13.5 | 11.5 | 9.5 | 7.5 | 5.5 | 3.5 | 2.5 | 2.5 | 2.5 | 1.5 |
| | 60 | 4.5 | 4.5 | 3.5 | 16.5 | 23.5 | 27.5 | 31.5 | 29.5 | 28.5 | 24.5 | 21.5 | 18.5 | 17.5 | 16.5 | 15.5 | 14.5 | 13.5 | 11.5 | 9.5 | 8.5 | 7.5 | 6.5 | 6.5 | 5.5 |
| | 100 | 10.5 | 10.5 | 9.5 | 9.5 | 9.5 | 14.5 | 19.5 | 20.5 | 21.5 | 22.5 | 21.5 | 19.5 | 17.5 | 16.5 | 15.5 | 14.5 | 13.5 | 13.5 | 13.5 | 12.5 | 12.5 | 11.5 | 11.5 | 10.5 |
| | 140 | 12.5 | 11.5 | 11.5 | 11.5 | 11.5 | 10.5 | 9.5 | 14.5 | 17.5 | 18.5 | 19.5 | 21.5 | 18.5 | 18.5 | 17.5 | 16.5 | 17.5 | 15.5 | 15.5 | 14.5 | 14.5 | 13.5 | 13.5 | 12.5 |
| South | 20 | 2.5 | 1.5 | -0.5 | 4.5 | 7.5 | 17.5 | 25.5 | 30.5 | 33.5 | 31.5 | 29.5 | 23.5 | 19.5 | 15.5 | 13.5 | 10.5 | 16.5 | 8.5 | 6.5 | 4.5 | 4.5 | 3.5 | 3.5 | 2.5 |
| | 60 | 2.5 | 3.5 | -0.5 | 0.5 | 1.5 | 10.5 | 15.5 | 23.5 | 27.5 | 28.5 | 29.5 | 26.5 | 23.5 | 18.5 | 15.5 | 13.5 | 11.5 | 9.5 | 7.5 | 5.5 | 4.5 | 4.5 | 3.5 | 2.5 |
| | 100 | 7.5 | 7.5 | 5.5 | 5.5 | 5.5 | 6.5 | 7.5 | 11.5 | 15.5 | 12.5 | 19.5 | 21.5 | 21.5 | 18.5 | 17.5 | 14.5 | 13.5 | 12.5 | 11.5 | 11.5 | 10.5 | 9.5 | 9.5 | 8.5 |
| | 140 | 10.5 | 9.5 | 9.5 | 8.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 10.5 | 13.5 | 16.5 | 17.5 | 18.5 | 19.5 | 19.5 | 17.5 | 15.5 | 13.5 | 13.5 | 12.5 | 12.5 | 11.5 | 10.5 |
| Southwest | 20 | 1.5 | -3.5 | -0.5 | 1.5 | 3.5 | 7.5 | 9.5 | 28.5 | 29.5 | 37.5 | 43.5 | 44.5 | 45.5 | 33.5 | 27.5 | 15.5 | 9.5 | 7.5 | 5.5 | 4.5 | 4.5 | 3.5 | 2.5 | 2.5 |
| | 60 | 5.5 | 4.5 | 3.5 | 3.5 | 3.5 | 4.5 | 5.5 | 11.5 | 15.5 | 27.5 | 35.5 | 38.5 | 39.5 | 39.5 | 37.5 | 23.5 | 13.5 | 10.5 | 9.5 | 5.5 | 7.5 | 7.5 | 6.5 | 6.5 |
| | 100 | 10.5 | 8.5 | 9.5 | 8.5 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 15.5 | 17.5 | 22.5 | 25.5 | 26.5 | 27.5 | 26.5 | 25.5 | 18.5 | 13.5 | 13.5 | 12.5 | 12.5 | 11.5 | 10.5 |
| | 140 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 10.5 | 9.5 | 9.5 | 9.5 | 10.3 | 11.5 | 12.5 | 13.5 | 18.5 | 21.5 | 22.5 | 23.5 | 16.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 |
| West | 20 | 1.5 | 0.5 | -0.5 | 1.5 | 5.5 | 6.5 | 9.5 | 17.5 | 23.5 | 35.5 | 43.5 | 48.5 | 51.5 | 37.5 | 25.5 | 17.5 | 11.5 | 8.5 | 5.5 | 4.5 | 3.5 | 3.5 | 2.5 | 2.5 |
| | 60 | 5.5 | 4.5 | 3.5 | 3.5 | 13.5 | 5.5 | 7.5 | 10.5 | 13.5 | 22.5 | 29.5 | 37.5 | 43.5 | 44.5 | 39.5 | 31.5 | 19.5 | 13.5 | 9.5 | 9.5 | 7.5 | 6.5 | 6.5 | 5.5 |
| | 100 | 10.5 | 10.5 | 9.5 | 9.5 | 9.5 | 9.5 | 9.5 | 10.5 | 11.5 | 13.5 | 15.5 | 20.5 | 23.5 | 28.5 | 31.5 | 30.5 | 23.5 | 22.5 | 17.5 | 15.5 | 14.5 | 13.5 | 12.5 | 11.5 |
| | 140 | 16.5 | 14.5 | 13.5 | 12.5 | 11.5 | 11.5 | 11.5 | 12.5 | 13.5 | 13.5 | 13.5 | 14.5 | 15.5 | 17.5 | 19.5 | 24.5 | 25.5 | 26.5 | 25.5 | 23.5 | 23.5 | 19.5 | 18.5 | 16.5 |
| Northwest | 20 | 0.5 | -0.5 | -0.5 | 0.5 | 3.5 | 6.5 | 9.5 | 13.5 | 15.5 | 22.5 | 27.5 | 36.5 | 45.5 | 40.5 | 37.5 | 21.5 | 19.5 | 9.5 | 5.5 | 3.5 | 2.5 | 2.5 | 1.5 | 1.5 |
| | 60 | 1.5 | 0.5 | -0.5 | 0.5 | 1.5 | 3.5 | 5.5 | 9.5 | 11.5 | 13.5 | 15.5 | 24.5 | 33.5 | 34.5 | 35.5 | 21.5 | 15.5 | 11.5 | 9.5 | 7.5 | 6.5 | 4.5 | 3.5 | 3.5 |
| | 100 | 3.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 8.5 | 6.5 | 12.5 | 15.5 | 20.5 | 23.5 | 24.5 | 25.5 | 17.5 | 11.5 | 10.5 | 11.5 | 9.5 | 9.5 | 8.5 |
| | 140 | 11.5 | 9.5 | 9.5 | 9.5 | 9.5 | 9.5 | 9.5 | 9.5 | 9.5 | 9.5 | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 17.5 | 21.5 | 23.5 | 23.5 | 19.5 | 16.5 | 14.5 | 13.5 | 12.5 |
| North (Shade) | 20 | 0.5 | -0.5 | 0.5 | -0.5 | 1.5 | 4.5 | 7.5 | 11.5 | 13.5 | 15.5 | 17.5 | 16.5 | 15.5 | 13.5 | 11.5 | 9.5 | 7.5 | 5.5 | 3.5 | 2.5 | 2.5 | 1.5 | 1.5 | 1.5 |
| | 60 | 0.5 | 0.5 | -0.5 | -0.5 | 1.5 | 2.5 | 3.5 | 9.5 | 9.5 | 11.5 | 13.5 | 14.5 | 15.5 | 15.5 | 15.5 | 12.5 | 11.5 | 9.5 | 7.5 | 5.5 | 4.5 | 3.5 | 2.5 | 1.5 |
| | 100 | 4.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 4.5 | 5.5 | 6.5 | 7.5 | 8.3 | 8.5 | 8.5 | 11.5 | 10.5 | 9.5 | 8.5 | 7.5 | 6.5 | 6.5 | 5.5 | 5.5 | 4.5 |
| | 140 | 4.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 4.5 | 5.5 | 6.5 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 10.5 | 9.5 | 7.5 | 5.5 | 5.5 | 5.5 | 4.5 |
| | SUN TIME | AM 6 | AM 7 | AM 8 | AM 9 | AM 10 | AM 11 | AM 12 | PM 1 | PM 2 | PM 3 | PM 4 | PM 5 | PM 6 | PM 7 | PM 8 | PM 9 | PM 10 | PM 11 | AM 12 | AM 1 | AM 2 | AM 3 | AM 4 | AM 5 |

Source: A lecture note on air conditioning design (24)

# Appendix H

Figure H.1 The Revised ASHRAE Comfort Chart




~~Revised ASHRAE Comfort Chart~~

**The ASHRAE Comfort Chart indicates the effect of different air temperatures and humidities on comfort. Studies showed little effect of humidity except at quite high humidities.**

APPENDIX I

SOME DETAILED CALCULATIONS FOR THE THERMAL SYSTEM

In this Appendix, the determination procedures for heat input to the boiler, heat output of the boiler, and steam requirement for each piece of equipment are illustrated.

I.1 <u>Determination of Heat Input to the Boiler</u>

1.1 Chemical heat in the fuel "as fired,"

$$Q_{fc} = (W_f)(H_l)$$

where $W_f$ = measured fuel rate, kg per hr;

$H_l$ = low-heating value, kcal per hr.

For this combustion chamber with the data obtained, we get $Q_{fc}$ = 1,732,500 kcal per hour.

1.2 Heat credit supplied by feedwater,

$$Q_w = (W_w)(C_{pw})(t_{fw}-t_i)$$

where $W_w$ = feedwater flow rate, kg per hr;

$C_{pw}$ = specific heat of feedwater, kcal per kg °C;

$t_{fw}$ = intake feedwater temperature, °C;

$t_i$ = reference temperature, 30 °C.

For the feedwater with the data obtained, we find $Q_w$ is equal 156,900 kcal per hour.

1.3 Heat credit supplied by preheated fuel oil,

$$Q_{fp} = (W_f)(C_f)(t_f - t_i)$$

where $C_f$ = specific heat of fuel oil, kcal per kg °C;

$t_f$ = temperature of fuel before combustion, °C;

other symbols as before.

For this fuel oil with the data obtained, we get $Q_{fp}$ equal 5481 kcal per hour.

I.2 Computation for the Output of the Boiler

2.1 Heat of steam produced, $Q_s = W_s(h_2 - h_1)$, where $W_s$ = net quantity of steam produced, kg per hr; $h_2$ = enthalpy* of steam leaving the boiler, kcal per kg; $h_1$ = enthalpy of water at reference temperature (30°C), kcal per kg. Here, we have $W_s = 2715$, $h_2 = 638.8$ (assume the steam quality be 0.95), and $h_1 = 30$. Then, $Q_s$ = 1,652,892 kcal per hour.

2.2 Heat loss due to dry flue gas:

For any boiler the dry-flue gas loss $Q_g$ kcal per hour is given by $Q_g = G.C_g.(t_g - t_i)$, where G = the amount of flue-gas, $Nm^3$ per kg of fuel; $C_g$ = average specific heat of dry-flue gas, kcal per $Nm^3$°C; $t_g$ = flue-gas exit temperature, °C; $t_i$ is as given previously.

To find G, we proceed as follows:

2.2.1 The air required by actual combustion, $A = m.A_o$ where $A_o$ = air required for complete combustion or theoretical air, $Nm^3$ per kg of fuel; m = excess air coefficient or air ratio. Using a

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*For this calculation, assume that the steam quality is 0.95.

formula suggested by Boie (9) and typical inspection values for the heavy fuel oil provided by the ESSO Standard Thailand Ltd,

$A_o = \frac{12.38(H_1-1100)}{10000}$ or 10.89 $Nm^3$ per kg of fuel when $H_1$ represents the low-heat value of 9900 Kcal per kg of fuel oil. The air ratio, on the other hand, may be calculated by $m = \frac{(CO_2)\ max}{(CO_2)}$, where $(CO_2)$ max is the volume fraction of carbon dioxide found from laboratory analysis. For fuel oil, this value is approximately 15.7 percent.* Since the measured percentage of $CO_2$ is 12.5,** the air ratio may be calculated as 1.256. Then, A = 1.256 x 10.87 = 13.68 $Nm^3$ per kg of fuel.

2.2.2 The amount of dry flue-gas, $G = G_o + (m-1)\ A_o$, where $G_o$ = theoretical dry flue-gas and may be estimated by a formula of Boie (9) as $G_o = \frac{15.75(H_1-1100)}{10000} - 2.18$ or 11.68 $Nm^3$ per kg of fuel. With this $G_o$, together with m and $A_o$ found in 2.2.1, G = 14.47 $Nm^3$ per kg of fuel.

Then, with G=14.47 $Nm^3$ per kg of fuel, $C_g$ = 0.332 kcal per $Nm^3$ °C, $t_g$ = 232 °C, and $t_i$ = 30 °C, the dry-flue gas loss is 169,824 kcal per hour for the given firing rate.

2.3 Heat loss due to blowdown, $Q_b = W_b\ C_b(t_b-t_i)$, where $W_b$ = quantity of blow, kg per hour; $C_b$ = specific heat of blow water, kcal per kg°C ; $t_b$ = temperature of the blowing water, °C; and $t_i$ as before. With the data obtained, $Q_b$ = 62,878 kcal per hour.

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*See Table 2.18, pp. 47 of the Thermal Energy Conservation Handbook (9).

**Data measured on a typical day of November 1985.

## I.3 Determination of Steam Consumption at Various Equipment

### 1. The Melting Tank

Caprolactam, 90% from the crush mill and 10% from the recovered lactam storage tank, is fed into the melting tank where a low pressure steam is supplied to its steam jacket to melt the material. A simplified diagram of this system is exhibited in Figure I.1.

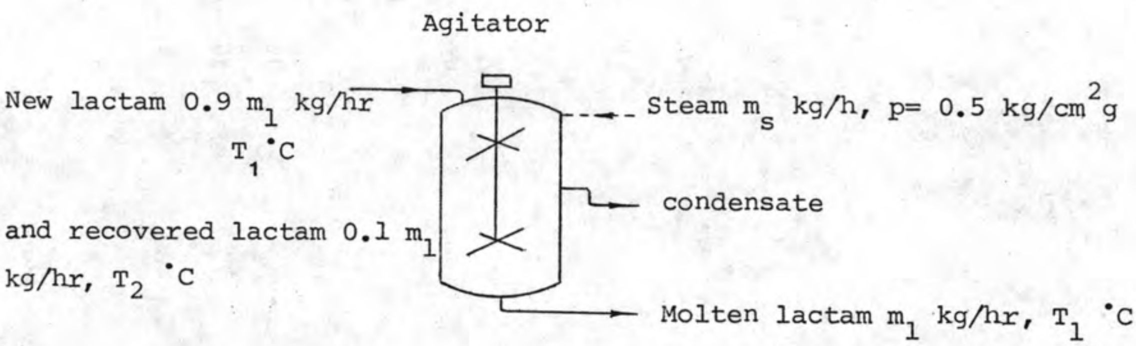


Figure I.1 Flow Diagram of the Melting Tank.

Applying the first law of thermodynamics to the tank,

$$\dot{m}_s q_s + W - Q = 0.9 \dot{m}_l C_l (T_l - T_1) + \dot{m}_l L_l$$

where $\dot{m}_s$, $\dot{m}_l$, 0.9 $\dot{m}_l$ = mass flow rate of steam, molten lactam and new lactam, respectively, kg/hr

$q_s$ = specific enthalpy of vaporization, kcal/kg

$W$ = electrical energy for the agitator, kcal/hr

$Q$ = heat loss from the tank, kcal/hr

$C_l$ = specific heat of solid lactam

$T_l$, $T_1$ = melting point of lactam, room temperature

$L_l$ = latent heat of solid lactam

yield $\dot{m}_s = 57$ kg/hr.

2. The Blending Tank

The molten caprolactam from the melting tank is transfered, batch by batch, into the blending tank in which water, acetic acid, as well as titanium dioxide are introduced. The system may be shown as Figure I.2.

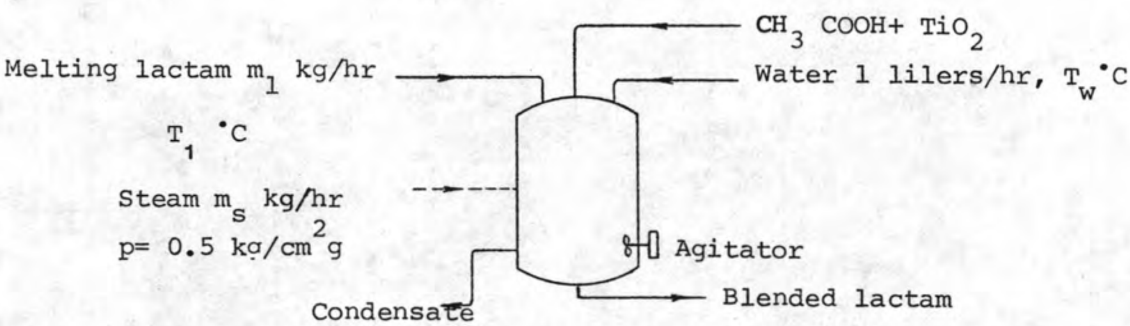


Figure I.2 Flow Diagram of the Blending Tank.

Applying the first law of thermodynamics to the blending tank,

$$\dot{m}_s q_s + W - Q = \dot{m}_w C_w (T_w - T_1)$$

where $\dot{m}_w, C_w, T_w$ = mass flow rate, specific heat, inlet water temperature of water and other symbols are the same as those described for the melting tank, we get $\dot{m}_s = 3.0$ kg/hr.

3. The Extraction Tower

After screening process, see Figure 3.2 and 3.3 the raw chip will be blown through a vertical pipe, via a channel at the upper zone, into the extraction tower. After that, lactam of about 11% of the raw chip, dissolved by circulating water, will be discharged to the wash-water collection tank while other 89%, in polymer form, is discharged to the wet chip storage bins. Figure I.3 exhibits the tower with three lines of low pressure steam.

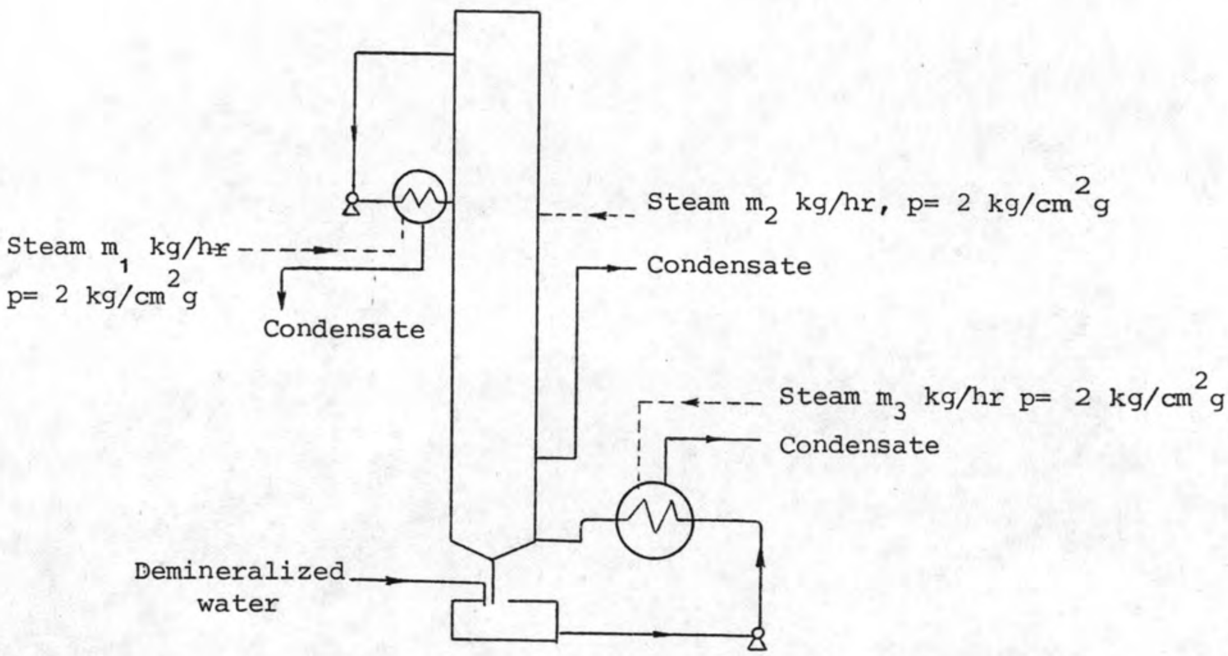


Figure I.3 Flow Diagram of the Extraction Tower.

By measuring condensate from the three steam traps, the total steam requirement of this tower is 129 kg/hr. Since there are two identical production lines, the amount of steam for this system may be calculated as 258 kg/hr.

4. The Evaporation System

Steam consumption in this system is that required by the first effect heat exchanger, by the steam ejector of the second effect, by the distillation kettle, and by steam ejectors of the distillation kettle. Descriptions for each item will be given as follows:

### 4.1 The First Effect Heat Exchanger

The following figure illustrates the system under consideration.

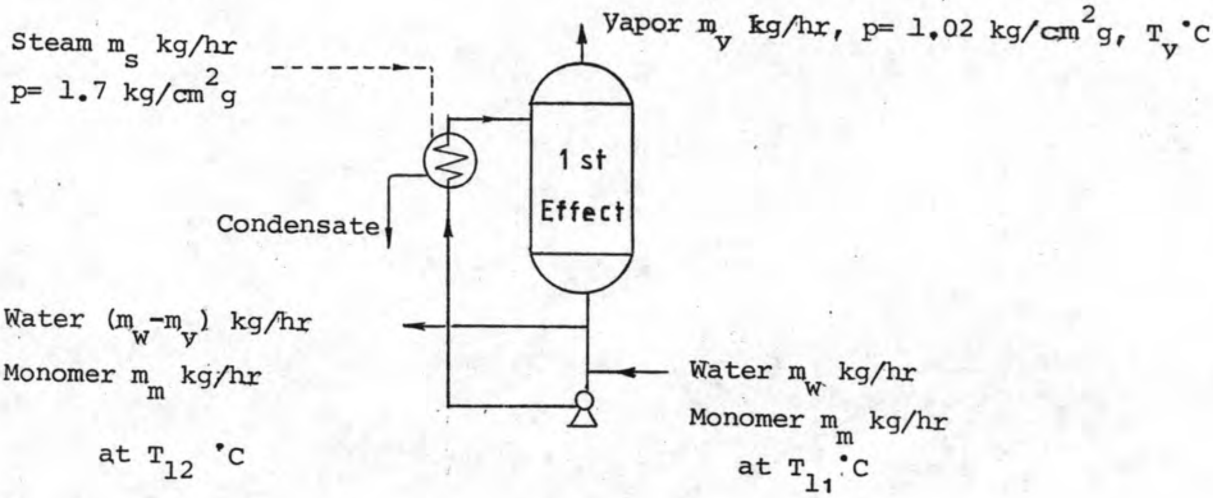


Figure I.4 Flow Diagram of the First Effect.

Applying the first law of thermodynamics to this system,

$$\dot{m}_s q_s + W - Q = -\dot{m}_w C_w (T_{11}-30) + \dot{m}_v (C_w (T_v-30) + L_w) + (\dot{m}_w - \dot{m}_v) h' + \dot{m}_m C_m (T_{12}-T_{11})$$

where $L_w$ = heat of water vaporization, kcal/kg

$\dot{m}_v$ = mass flow rate of vapor, kg/hr.

$C_m$ = specific heat of monomer, kcal/kg°C

$h'$ = specific enthalpy of saturated water, kcal/kg

and other symbols as before, we get $\dot{m}_s$ = 766 kg per hr.

### 4.2 The Steam Ejector of the Second Effect

This ejector is of single stage. Calculations for steam requirement can be made by the procedure given in the Pumping of Liquids and Gases (19), pages 6-29 to 6-34. An illustration of this system is shown by the following figure.

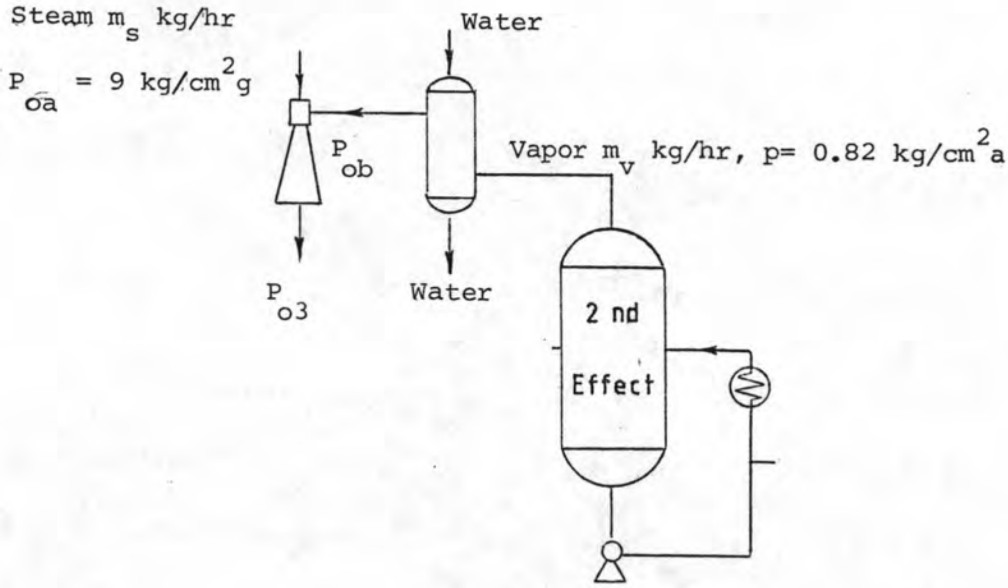


Figure I.5 Flow Diagram of the Single Stage Ejector.

In this figure, $p_{03}$ = discharge pressure = 760 Torr, $p_{oa}$ = motive gas pressure = 9 kg per cm$^2$ g, and $p_{ob}$ = suction pressure = 623 Torr. Enters the chart, see Figure I.6*, with $p_{03}/p_{ob}$ = 760/623 = 1.22 and $p_{ob}/p_{oa}$ = 623/(9x760) = 0.091 to obtain the optimum area ratio, $A_2/A_t$ = 60. Proceeding horizontally to the left, we find that $w_b/w_a$, mass ratio, is approximately 5.5 kg of air per kg of steam. This value, however, must be corrected for temperature and molecular weight differences of the two fluids, vapor and steam, by the equation $\left(\frac{w_b}{w_a}\right)' = \frac{w_b}{w_a}\sqrt{\frac{T_{oa}\ M_b}{T_{ob}\ M_a}}$, where $T_{oa}$ = temperature of steam = 179°C, $T_{ob}$ = temperature of vapor = 94.4°C, and $M_a$ and $M_b$ are molecular weights of steam and vapor, respectively, which are assumed to be equal. Therefore, $\left(\frac{w_b}{w_a}\right)'$ = 7.57 or the steam flow rate, $w_a'$ = $\frac{725.92}{7.57}$ = 96 kg per hr.

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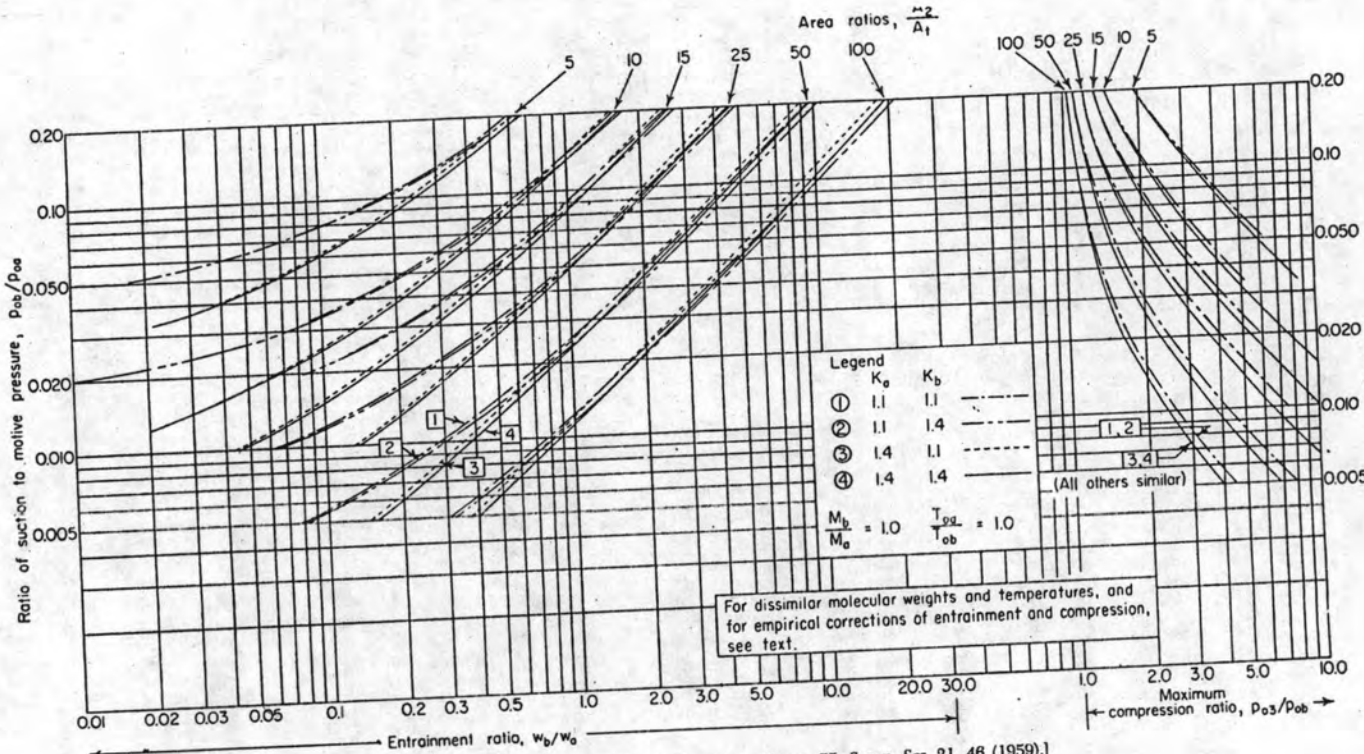
*This figure is Figure 6.72 in the Pumping of Liquids and Gases (19)




Optimum design curves for single-stage ejectors. [*DeFrate and Hoerl, Chem. Eng. Progr.*, **55**, *Symp. Ser.* 21, 46 (1959).]

Figure I.6 Optimum Design Curves for Single-Stage Ejectors.

## 4.3 The Distillation Kettle

In this system, a batch of mixture with 55% monomer weighs 6100 kg is distilled until caprolactam of 2000 kg is obtained. A flow diagram of this equipment is illustrated in Figure I.7.

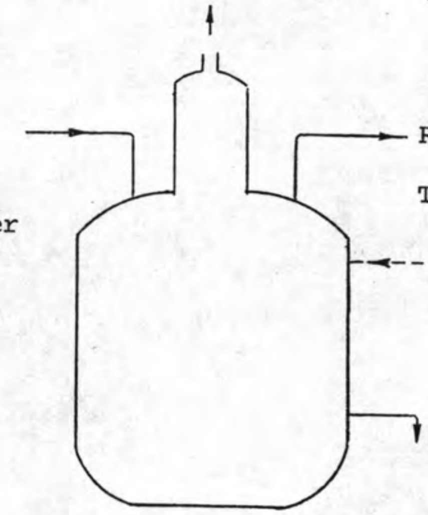



Figure I.7 Flow Diagram of the Distillation Kettle.

Applying the first law of thermodynamics to the kettle,

$$\dot{m}_s q_s - Q = \frac{1}{t}\left[ \dot{m}_w \left\{ C_w (T_{r1}-T_{mx}) + L_w \right\} + \dot{m}_{lo} \left\{ C_{lo} (T_{r2}-T_{mx}) + L_{lo} \right\} + m_k C_k (T_{r2}-T_i) \right],$$

where $t$ = cycle time or batch time, hr; $T_{r1}$, $T_{r2}$ = temperature of recovered lactam at the first and second stage, respectively, °C; $T_{mx}$ = temperature of the mixture of lactam, oligomer and water, °C; $L_w$ = heat of water vaporization, kcal per kg; $\dot{m}_{lo}$ = mass flow rate of lactam and oligomer, kg per hr; $C_{lo}$ = specific heat of lactam and oligomer, kcal per kg °C; $L_{lo}$ = heat of lactam vaporization, kcal per kg; $m_k$ = mass of the kettle, kg; $C_k$ = specific heat of the kettle, kcal per kg °C, and other symbols are as before. Therefore, steam consumption for the process at this equipment, $m_s$, is approximately 98 kg per hr.

### 4.4 Steam Ejectors of the Distillation Kettle

This equipment has a two-stage ejector with suction pressure of 10 Torr and requires steam pressure of 9 kg per $cm^2$ g. The operating cycle at this process is 48 hr, 33 hr of actual operation and 15 hr of idle time. A flow diagram for this equipment is exhibited in Figure I.8.

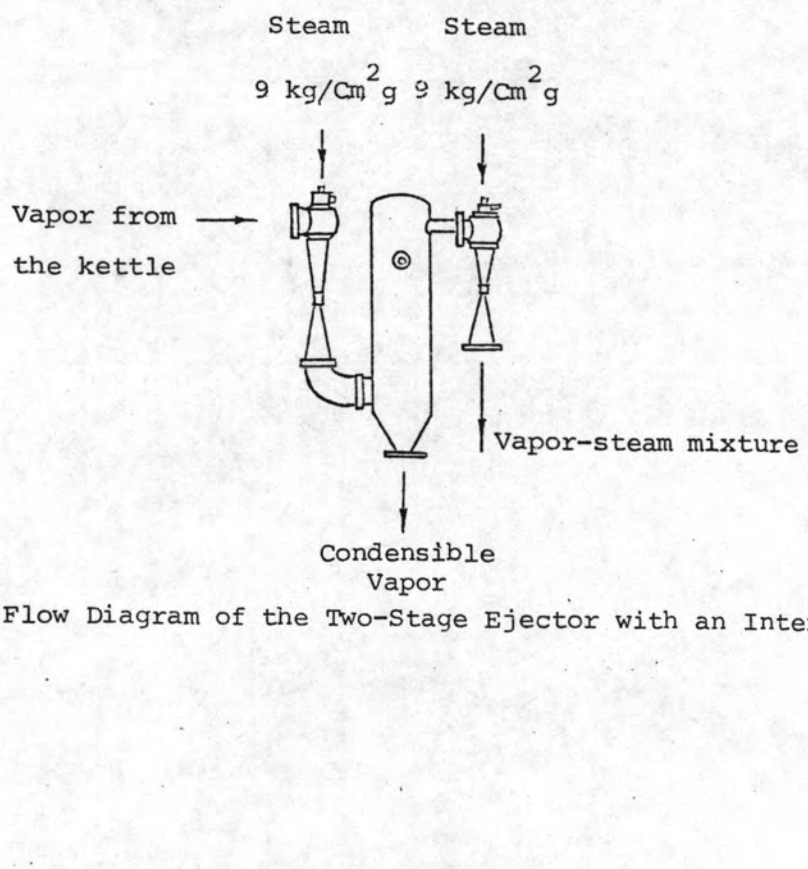



Figure 1.8 Flow Diagram of the Two-Stage Ejector with an Inter-Condenser.

An estimation was done to find steam consumption of this equipment using the performance curve and table provided by Roger G. Mote in his study of the Jet Ejectors and Condensers as Vacuum Producing Devices which is published in Chapter 5 of the Process Equipment Series Volume 3 (20)*.

By this method, steam requirement of this equipment is 124 kg per hr.

5. <u>The Vacuum Dryers</u>

Four sets of the dryer have been employed for the manufacturing process. Each dryer consists of a dryer drum and a three-stage ejector consuming steam of 9 kg per $cm^2$ g. The overall operating cycle is 24 hours including 8 hours of two-stage ejector running at 40 Torr suction pressure, 7 hours of three-stage ejector at 5 Torr suction pressure, and 9 hours of idle time waiting for the next batch of material to come. A simplified diagram representing this group of equipment is shown in Figure I.9.

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*As indicated in the curves, Figure 5.45 and 5.46 of the stated reference, the suction pressure of 10 Torr corresponds to the zone of TABLE A in Figure 5.45. For steam pressure of 9 kg per $cm^2$ g and capacity factor of 4.0, assumed for the highest capacity, Figure 5.46 gives steam motive requirements of about 180.5 kg per hr. Then, steam consumption of this equipment averaged for the cycle time of 48 hr, with 33 hr of actual operation, is $180.5 \times \frac{33}{48} = 124$ kg per hr.

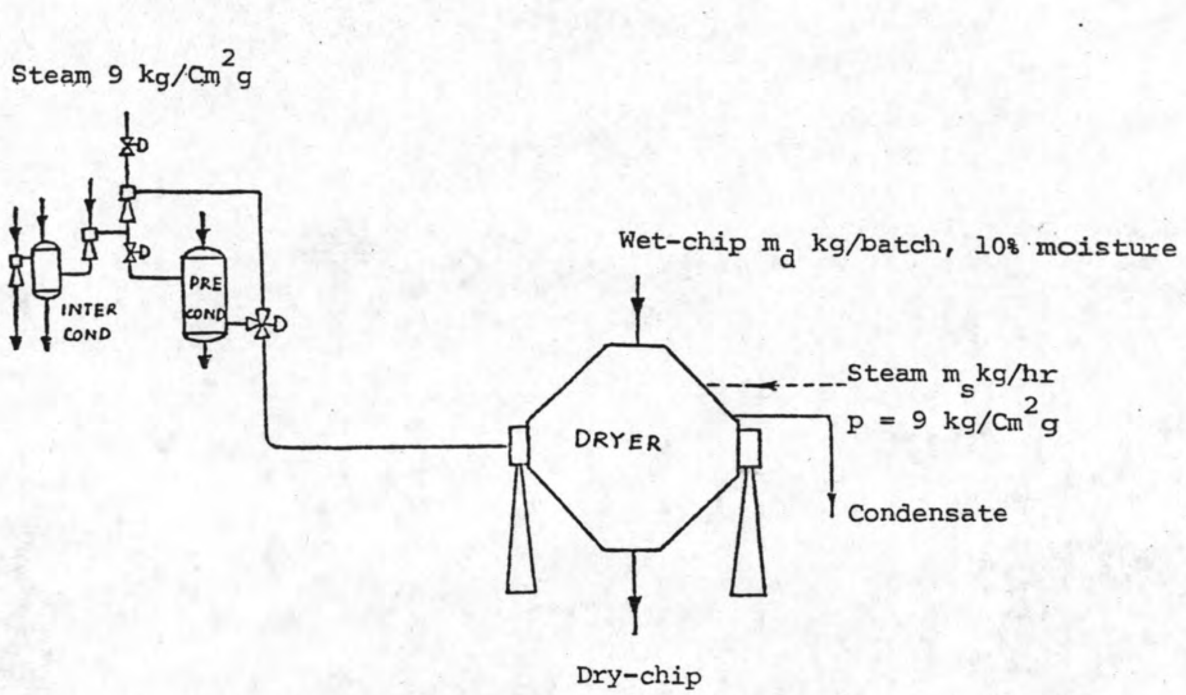


Figure I.9 Flow Diagram of the Dryer and Its Ejector System

At the dryer, a batch of wet chip of 3000 kg with 10% moisture content is transfered from the wet chip storage bin (see Figure 3.2). The drying process continues until the final moisture content of 0.02% is attained. This process requires the two-stage ejector to obtain the moisture level of 1.0% and the three-stage to obtain the rest.

Calculation for steam consumption of the dryer (excluding the ejector system) may be accomplished by applying the first law of thermodynamics,

$$\dot{m}_s q_s + W - Q = \frac{1}{24} m_d C_d (T_d - T_i) + 0.9 \dot{m}_c C_c (T_d - T_i) + 0.0998 \dot{m}_c \left[ (C_w (T_d - T_i) + L_w) \right]$$

where W = electric energy for the dryer motor, $m_d$ = mass of the dryer, $C_d$ = specific heat of the dryer, $T_d$ = final temperature of

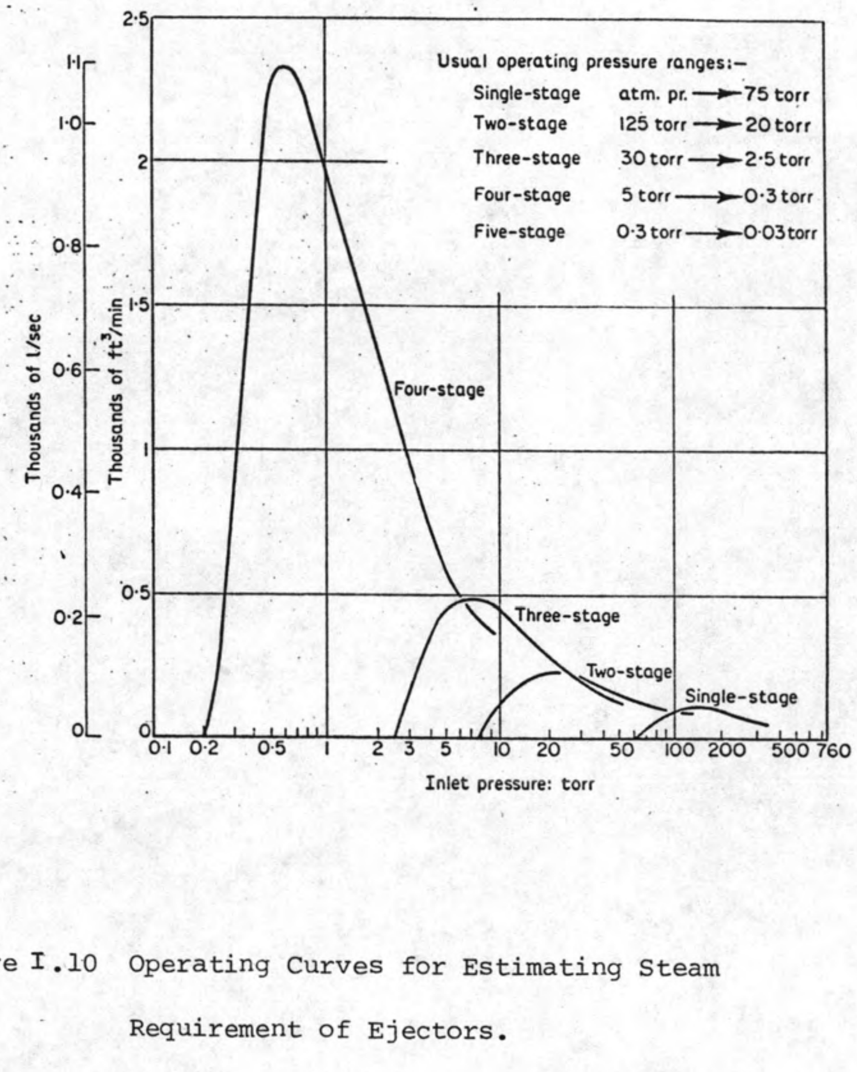


Figure I.10 Operating Curves for Estimating Steam Requirement of Ejectors.

drying process, $\dot{m}_c$ = mass flow rate of the chip, $C_c$ = specific heat of the chip, and other symbols as before. Then, steam requirement of the dryer, excluding the ejector system, is 39.8 kg per hr.

The steam requirement of the evaptor air pump (ejector), on the other hand, can be determined indirectly using the chart given in Figure I.10.*

For the four sets of vacuum dryers of the manufacturing process, the total amount of steam requirement is 4 x (39.8 + 161.5) = 805 kg per hr.

6 The Finishing Tower Steam Ejectors

There are two sets of single-stage steam ejector installed for the two finishing towers to pump out their dowterm vapor. Using the result found in 4.2, steam required by the FNT ejectors is approximately 2 x 95.89 = 192 kg per hr.

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*This is the chart given in Figure 4.2a on page 50 of the High Vacuum Pumping Equipment (21). Refering to this figure, with the suction pressure of 40 Torr for the two-stage ejector and of 5 Torr for the three-stage one, the volumetric speed of 278 and 236kg per hr, respectively, are obtained. Using these two figures as steam estimates for the two operations, the average steam consumption for the ejector system is (8 x 278 + 7 x 236)/24 = 161.5 kg per hr.

7. The Take-Up Air Washer

Steam is utilized by the air washer to control the relative humidity of cooling air as described in chapter 6. The steam flow rate into this equipment is easily measured by its condensate flowing out. A measurement taken in late January 1986 indicated that the steam flow rate was about 122 kg per hr.

8. The Take-Up Finish Oil Tank

There are two types of fiber being produced in the factory, 40/10 and 70/10, each of which requires difference mixture of finish oil.

Steam is used to raise the temperature of each mixture from 20°C to 50°C. The heat load of this system is approximately $(3\,\dot{m}_1 + 2\,\dot{m}_2)\cdot(C_m)(50\text{-}20)$, where $\dot{m}_1$ and $\dot{m}_2$ are mass flow rate, kg per hr, of the mixture for the two types of fiber; $C_m$ is specific heat of each mixture, in this case, assumed to be 1 kcal per kg°C. With pressure of 2 kg per $cm^2$g, the steam consumed by this tank is 4 kg per hr.

9. The Deaerator

Steam is used in this equipment to eliminate $O_2$, $CO_2$, $H_2S$, and other gases in feedwater. Based on data in Table 7.1, the steam required by this process is 298 kg per hr.

10. The Oil Preheater

Heavy fuel oil from the storage tank is preheated first by steam flashed from the blowdown to raise its temperature upto about 40°C and then by boiler's steam and electric heater. The oil temperature after the two latter heat sources is about 110°C. A flow diagram at the preheater may be illustrated as folows.

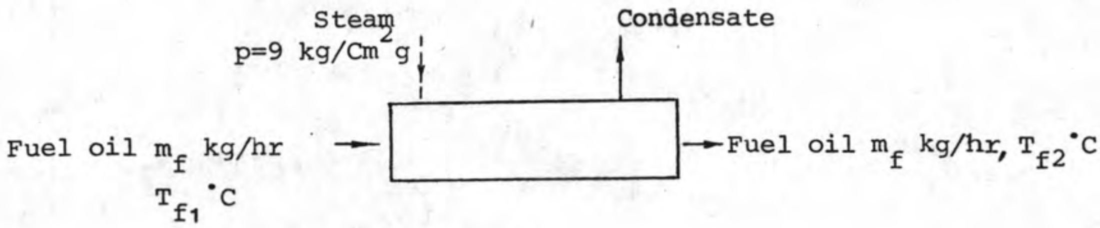


Figure I.11 Flow Diagram of the Oil Preheater.

Applying the first law of thermodynamics to the preheater

$$\dot{m}_s q_s - Q = \dot{m}_f C_f (T_{f2} - T_{f1}),$$

where $\dot{m}_f$, $C_f$, $T_{f1}$ and $T_{f2}$ are mass flow rate (kg/hr), specific heat (kcal/kg°C), inlet temperature (°C), and outlet temperature (°C), respectively, of the fuel oil; other symbols as before. The steam consumption of this preheater of about 16 kg per hr is estimated.

11. <u>The Burn Out Furnace</u>

The furnace has been used to clean the spinerette and accessories of process equipment. The quantity of steam sprayed into this burner can be estimated by $\dot{m}_s = 900\pi\gamma d^2 u$, where $\dot{m}_s$ = steam flow rate, kg per hr; $\gamma$ = specific gravity of steam, kg per $m^3$; d = inner diameter of the pipe, m; and u = steam velocity in the pipe, pipe, m per see. With $\gamma$ = 5.053 kg per $m^3$, d = 0.0127 m, u = 20 m per sec, from Table 5.3 of the Thermal Energy Conservation Handbook (9), steam flow rate is 46 kg per hr. Since the furnace runs 4 hours per day, steam consumption is approximately 8 kg per hr.

Table I.1 Properties of Saturated Steam

| Pressure P (kg/cm$^2$) | Temperature (°C) | Volume ($m^3$/kg) | | Enthalpy (kcal/kg) | | | Entropy (kcal/kg°K) | |
|---|---|---|---|---|---|---|---|---|
| | | v′ | v′′ | h′ | h′′ | r | s′ | s′′ |
| 1.0 | 99.09 | 0.0010430 | 1.725 | 99.17 | 638.8 | 539.6 | 0.3097 | 1.7594 |
| 1.033 | 100.00 | 0.0010437 | 1.673 | 100.09 | 639.2 | 539.1 | 0.3121 | 1.7568 |
| 1.2 | 104.25 | 0.0010471 | 1.454 | 104.37 | 640.7 | 536.4 | 0.3235 | 1.7448 |
| 1.4 | 108.74 | 0.0010508 | 1.259 | 108.91 | 642.4 | 533.5 | 0.3355 | 1.7324 |
| 1.6 | 112.73 | 0.0010542 | 1.111 | 112.94 | 643.8 | 530.8 | 0.3460 | 1.7217 |
| 1.8 | 116.33 | 0.0010573 | 0.9952 | 116.59 | 645.0 | 528.5 | 0.3554 | 1.7122 |
| 2.0 | 119.61 | 0.0010603 | 0.9018 | 119.92 | 646.2 | 526.3 | 0.3639 | 1.7038 |
| 2.2 | 122.64 | 0.0010631 | 0.8249 | 123.00 | 647.2 | 524.2 | 0.3717 | 1.6961 |
| 2.6 | 128.08 | 0.0010682 | 0.7053 | 128.53 | 649.0 | 520.5 | 0.3855 | 1.6828 |
| 3.0 | 132.88 | 0.0010728 | 0.6168 | 133.42 | 650.9 | 517.2 | 0.3976 | 1.6713 |
| 4 | 142.92 | 0.0010831 | 0.4708 | 143.70 | 653.7 | 510.0 | 0.4226 | 1.6483 |
| 5 | 151.11 | 0.0010920 | 0.3816 | 152.13 | 656.0 | 503.9 | 0.4426 | 1.6303 |
| 6 | 158.08 | 0.0011000 | 0.3213 | 159.34 | 657.9 | 498.6 | 0.4594 | 1.6156 |
| 7 | 164.17 | 0.0011072 | 0.2778 | 165.67 | 659.5 | 493.8 | 0.4739 | 1.6031 |
| 8 | 169.61 | 0.0011140 | 0.2448 | 171.35 | 660.8 | 489.5 | 0.4867 | 1.5922 |
| 9 | 171.45 | 0.0011203 | 0.2183 | 176.51 | 661.9 | 485.4 | 0.4983 | 1.5826 |
| 10 | 179.04 | 0.0011262 | 0.1979 | 181.25 | 662.9 | 481.7 | 0.5087 | 1.5739 |
| 11 | 183.20 | 0.0011319 | 0.1807 | 185.65 | 663.7 | 478.1 | 0.5184 | 1.5660 |
| 12 | 187.08 | 0.0011373 | 0.1663 | 189.77 | 664.5 | 474.7 | 0.5273 | 1.5588 |
| 13 | 190.71 | 0.0011425 | 0.1540 | 193.63 | 665.1 | 471.5 | 0.5356 | 1.5521 |
| 14 | 194.13 | 0.0011476 | 0.1434 | 197.29 | 665.7 | 468.4 | 0.5434 | 1.5468 |
| 15 | 197.37 | 0.0011524 | 0.1342 | 200.75 | 666.2 | 465.5 | 0.5507 | 1.510 |
| 16 | 200.43 | 0.0011572 | 0.1260 | 204.05 | 666.7 | 462.6 | 0.5577 | 1.5345 |
| 17 | 203.36 | 0.0011618 | 0.1189 | 207.21 | 667.1 | 459.9 | 0.5642 | 1.5293 |
| 18 | 206.15 | 0.0011663 | 0.1124 | 210.23 | 667.4 | 457.2 | 0.5705 | 1.5244 |
| 19 | 208.82 | 0.0011706 | 0.1067 | 213.14 | 667.7 | 454.6 | 0.5765 | 1.5197 |
| 20 | 221.39 | 0.0011749 | 0.1015 | 215.94 | 668.0 | 452.1 | 0.5822 | 1.5152 |

Table 1.2 1 % Interest Factors for Discrete Compounding Periods.

| | SINGLE PAYMENT | | UNIFORM PAYMENT SERIES | | | | GRADIENT SERIES | |
|---|---|---|---|---|---|---|---|---|
| | Compound Amount Factor | Present Worth Factor | Present Worth Factor | Capital Recovery Factor | Compound Amount Factor | Sinking Fund Factor | Gradient Uniform Series | Gradient Present Worth |
| *N* | Find *F* Given *P* *F/P* | Find *P* Given *F* *P/F* | Find *P* Given *A* *P/A* | Find *A* Given *P* *A/P* | Find *F* Given *A* *F/A* | Find *A* Given *F* *A/F* | Find *A* Given *G* *A/G* | Find *P* Given *G* *P/G* |
| 1 | 1.010 | 0.9901 | 0.9901 | 1.0100 | 1.000 | 1.0000 | 0.0000 | 0.000 |
| 2 | 1.020 | 0.9803 | 1.9704 | 0.5075 | 2.010 | 0.4975 | 0.4975 | 0.980 |
| 3 | 1.030 | 0.9706 | 2.9410 | 0.3400 | 3.030 | 0.3300 | 0.9934 | 2.921 |
| 4 | 1.041 | 0.9610 | 3.9020 | 0.2563 | 4.060 | 0.2463 | 1.4876 | 5.804 |
| 5 | 1.051 | 0.9515 | 4.8534 | 0.2060 | 5.101 | 0.1960 | 1.9801 | 9.610 |
| 6 | 1.062 | 0.9420 | 5.7955 | 0.1725 | 6.152 | 0.1625 | 2.4710 | 14.321 |
| 7 | 1.072 | 0.9327 | 6.7282 | 0.1486 | 7.214 | 0.1386 | 2.9602 | 19.917 |
| 8 | 1.083 | 0.9235 | 7.6517 | 0.1307 | 8.286 | 0.1207 | 3.4478 | 26.381 |
| 9 | 1.094 | 0.9143 | 8.5660 | 0.1167 | 9.369 | 0.1067 | 3.9337 | 33.696 |
| 10 | 1.105 | 0.9053 | 9.4713 | 0.1056 | 10.462 | 0.0956 | 4.4179 | 41.843 |
| 11 | 1.116 | 0.8963 | 10.3676 | 0.0965 | 11.567 | 0.0865 | 4.9005 | 50.807 |
| 12 | 1.127 | 0.8874 | 11.2551 | 0.0888 | 12.683 | 0.0788 | 5.3815 | 60.569 |
| 13 | 1.138 | 0.8787 | 12.1337 | 0.0824 | 13.809 | 0.0724 | 5.8607 | 71.113 |
| 14 | 1.149 | 0.8700 | 13.0037 | 0.0769 | 14.947 | 0.0669 | 6.3384 | 82.422 |
| 15 | 1.161 | 0.8613 | 13.8651 | 0.0721 | 16.097 | 0.0621 | 6.8143 | 94.481 |
| 16 | 1.173 | 0.8528 | 14.7179 | 0.0679 | 17.258 | 0.0579 | 7.2886 | 107.273 |
| 17 | 1.184 | 0.8444 | 15.5623 | 0.0643 | 18.430 | 0.0543 | 7.7613 | 120.783 |
| 18 | 1.196 | 0.8360 | 16.3983 | 0.0610 | 19.615 | 0.0510 | 8.2323 | 134.996 |
| 19 | 1.208 | 0.8277 | 17.2260 | 0.0581 | 20.811 | 0.0481 | 8.7017 | 149.895 |
| 20 | 1.220 | 0.8195 | 18.0456 | 0.0554 | 22.019 | 0.0454 | 9.1694 | 165.466 |
| 21 | 1.232 | 0.8114 | 18.8570 | 0.0530 | 23.239 | 0.0430 | 9.6354 | 181.695 |
| 22 | 1.245 | 0.8034 | 19.6604 | 0.0509 | 24.472 | 0.0409 | 10.0998 | 198.566 |
| 23 | 1.257 | 0.7954 | 20.4558 | 0.0489 | 25.716 | 0.0389 | 10.5626 | 216.066 |
| 24 | 1.270 | 0.7876 | 21.2434 | 0.0471 | 26.973 | 0.0371 | 11.0237 | 234.180 |
| 25 | 1.282 | 0.7798 | 22.0232 | 0.0454 | 28.243 | 0.0354 | 11.4831 | 252.894 |
| 26 | 1.295 | 0.7720 | 22.7952 | 0.0439 | 29.526 | 0.0339 | 11.9409 | 272.196 |
| 27 | 1.308 | 0.7644 | 23.5596 | 0.0424 | 30.821 | 0.0324 | 12.3971 | 292.070 |
| 28 | 1.321 | 0.7568 | 24.3164 | 0.0411 | 32.129 | 0.0311 | 12.8516 | 312.505 |
| 29 | 1.335 | 0.7493 | 25.0658 | 0.0399 | 33.450 | 0.0299 | 13.3044 | 333.486 |
| 30 | 1.348 | 0.7419 | 25.8077 | 0.0387 | 34.785 | 0.0287 | 13.7557 | 355.002 |
| 31 | 1.361 | 0.7346 | 26.5423 | 0.0377 | 36.133 | 0.0277 | 14.2052 | 377.039 |
| 32 | 1.375 | 0.7273 | 27.2696 | 0.0367 | 37.494 | 0.0267 | 14.6532 | 399.586 |
| 33 | 1.389 | 0.7201 | 27.9897 | 0.0357 | 38.869 | 0.0257 | 15.0995 | 422.629 |
| 34 | 1.403 | 0.7130 | 28.7027 | 0.0348 | 40.258 | 0.0248 | 15.5441 | 446.157 |
| 35 | 1.417 | 0.7059 | 29.4086 | 0.0340 | 41.660 | 0.0240 | 15.9871 | 470.158 |
| 36 | 1.431 | 0.6989 | 30.1075 | 0.0332 | 43.077 | 0.0232 | 16.4285 | 494.621 |
| 37 | 1.445 | 0.6920 | 30.7995 | 0.0325 | 44.508 | 0.0225 | 16.8682 | 519.533 |
| 38 | 1.460 | 0.6852 | 31.4847 | 0.0318 | 45.953 | 0.0218 | 17.3063 | 544.884 |
| 39 | 1.474 | 0.6784 | 32.1630 | 0.0311 | 47.412 | 0.0211 | 17.7428 | 570.662 |
| 40 | 1.489 | 0.6717 | 32.8347 | 0.0305 | 48.886 | 0.0205 | 18.1776 | 596.856 |

Table 1.3 12 % Interest Factors for Discrete Compounding Periods.

| | SINGLE PAYMENT | | UNIFORM PAYMENT SERIES | | | | GRADIENT SERIES | |
|---|---|---|---|---|---|---|---|---|
| | Compound Amount Factor | Present Worth Factor | Present Worth Factor | Capital Recovery Factor | Compound Amount Factor | Sinking Fund Factor | Gradient Uniform Series | Gradient Present Worth |
| N | Find F Given P F/P | Find P Given F P/F | Find P Given A P/A | Find A Given P A/P | Find F Given A F/A | Find A Given F A/F | Find A Given G A/G | Find P Given G P/G |
| 1 | 1.120 | 0.8929 | 0.8929 | 1.1200 | 1.000 | 1.0000 | 0.0000 | 0.000 |
| 2 | 1.254 | 0.7972 | 1.6901 | 0.5917 | 2.120 | 0.4717 | 0.4717 | 0.797 |
| 3 | 1.405 | 0.7118 | 2.4018 | 0.4163 | 3.374 | 0.2963 | 0.9246 | 2.221 |
| 4 | 1.574 | 0.6355 | 3.0373 | 0.3292 | 4.779 | 0.2092 | 1.3589 | 4.127 |
| 5 | 1.762 | 0.5674 | 3.6048 | 0.2774 | 6.353 | 0.1574 | 1.7746 | 6.397 |
| 6 | 1.974 | 0.5066 | 4.1114 | 0.2432 | 8.115 | 0.1232 | 2.1720 | 8.930 |
| 7 | 2.211 | 0.4523 | 4.5638 | 0.2191 | 10.089 | 0.0991 | 2.5515 | 11.644 |
| 8 | 2.476 | 0.4039 | 4.9676 | 0.2013 | 12.300 | 0.0813 | 2.9131 | 14.471 |
| 9 | 2.773 | 0.3606 | 5.3282 | 0.1877 | 14.776 | 0.0677 | 3.2574 | 17.356 |
| 10 | 3.106 | 0.3220 | 5.6502 | 0.1770 | 17.549 | 0.0570 | 3.5847 | 20.254 |
| 11 | 3.479 | 0.2875 | 5.9377 | 0.1684 | 20.655 | 0.0484 | 3.8953 | 23.129 |
| 12 | 3.896 | 0.2567 | 6.1944 | 0.1614 | 24.133 | 0.0414 | 4.1897 | 25.952 |
| 13 | 4.363 | 0.2292 | 6.4235 | 0.1557 | 28.029 | 0.0357 | 4.4683 | 28.702 |
| 14 | 4.887 | 0.2046 | 6.6282 | 0.1509 | 32.393 | 0.0309 | 4.7317 | 31.362 |
| 15 | 5.474 | 0.1827 | 6.8109 | 0.1468 | 37.280 | 0.0268 | 4.9803 | 33.920 |
| 16 | 6.130 | 0.1631 | 6.9740 | 0.1434 | 42.753 | 0.0234 | 5.2147 | 36.367 |
| 17 | 6.866 | 0.1456 | 7.1196 | 0.1405 | 48.884 | 0.0205 | 5.4353 | 38.697 |
| 18 | 7.690 | 0.1300 | 7.2497 | 0.1379 | 55.750 | 0.0179 | 5.6427 | 40.908 |
| 19 | 8.613 | 0.1161 | 7.3658 | 0.1358 | 63.440 | 0.0158 | 5.8375 | 42.998 |
| 20 | 9.646 | 0.1037 | 7.4694 | 0.1339 | 72.052 | 0.0139 | 6.0202 | 44.968 |
| 21 | 10.804 | 0.0926 | 7.5620 | 0.1322 | 81.699 | 0.0122 | 6.1913 | 46.819 |
| 22 | 12.100 | 0.0826 | 7.6446 | 0.1308 | 92.503 | 0.0108 | 6.3514 | 48.554 |
| 23 | 13.552 | 0.0738 | 7.7184 | 0.1296 | 104.603 | 0.0096 | 6.5010 | 50.178 |
| 24 | 15.179 | 0.0659 | 7.7843 | 0.1285 | 118.155 | 0.0085 | 6.6406 | 51.693 |
| 25 | 17.000 | 0.0588 | 7.8431 | 0.1275 | 133.334 | 0.0075 | 6.7708 | 53.105 |
| 26 | 19.040 | 0.0525 | 7.8957 | 0.1267 | 150.334 | 0.0067 | 6.8921 | 54.418 |
| 27 | 21.325 | 0.0469 | 7.9426 | 0.1259 | 169.374 | 0.0059 | 7.0049 | 55.637 |
| 28 | 23.884 | 0.0419 | 7.9844 | 0.1252 | 190.699 | 0.0052 | 7.1098 | 56.767 |
| 29 | 26.750 | 0.0374 | 8.0218 | 0.1247 | 214.583 | 0.0047 | 7.2071 | 57.814 |
| 30 | 29.960 | 0.0334 | 8.0552 | 0.1241 | 241.333 | 0.0041 | 7.2974 | 58.782 |
| 31 | 33.555 | 0.0298 | 8.0850 | 0.1237 | 271.293 | 0.0037 | 7.3811 | 59.676 |
| 32 | 37.582 | 0.0266 | 8.1116 | 0.1233 | 304.848 | 0.0033 | 7.4586 | 60.501 |
| 33 | 42.092 | 0.0238 | 8.1354 | 0.1229 | 342.429 | 0.0029 | 7.5302 | 61.261 |
| 34 | 47.143 | 0.0212 | 8.1566 | 0.1226 | 384.521 | 0.0026 | 7.5965 | 61.961 |
| 35 | 52.800 | 0.0189 | 8.1755 | 0.1223 | 431.663 | 0.0023 | 7.6577 | 62.605 |
| 36 | 59.136 | 0.0169 | 8.1924 | 0.1221 | 484.463 | 0.0021 | 7.7141 | 63.197 |
| 37 | 66.232 | 0.0151 | 8.2075 | 0.1218 | 543.599 | 0.0018 | 7.7661 | 63.741 |
| 38 | 74.180 | 0.0135 | 8.2210 | 0.1216 | 609.831 | 0.0016 | 7.8141 | 64.239 |
| 39 | 83.081 | 0.0120 | 8.2330 | 0.1215 | 684.010 | 0.0015 | 7.8582 | 64.697 |
| 40 | 93.051 | 0.0107 | 8.2438 | 0.1213 | 767.091 | 0.0013 | 7.8988 | 65.116 |

# BIO-DATA

Mr. Sanguan Taungbodhitham received his Bachelor's Degree in Industrial Engineering from Prince of Songkla University in 1979. He had attended Chulalongkorn University for his graduate study since June 1984 and completed his Master's Degree in Industrial Engineering in October 1986.

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