# MODIFIED T-METHOD DUCT DESIGN FOR USE IN THAILAND

*Dr. Chirdpun Vitooraporn*
*Lecturer*
*Department of Mechanical Engineering,*
*Chulalongkorn University, Bangkok, Thailand*

*Mr. Phichai Kritmaitree*
*Former Graduate Student*
*Department of Mechanical Engineering,*
*Chulalongkorn University, Bangkok, Thailand*

## Abstract

T-Method duct design is the procedure to determine the optimum duct system based on minimizing the system life cycle cost which is the objective function of the system. In this method, duct sizes are selected so that the minimum system life cycle cost is assured. In addition, the resulting system will also follow constraint conditions that are set by the air distribution requirement of the duct system.

In this research, we have modified this T-Method duct design to gain more efficiency and suitability for use in Thailand. This is done by modifying the objective function to include the energy loss, i.e. the heat transfer through duct wall, and the unit cost of duct construction which is varied according to duct sizes.

The results from the modified method were compared with those from other methods such as the equal friction method, the static regain method, and the conventional T-Method. It is found that under the same requirement on the same duct system, the duct system which is designed by the modified method gives the minimum life cycle cost. The reduction is as low as 13.5 percent when compared with that based on the conventional T-Method.

## 1. Introduction

Air distribution is one of the most important concerns for controlling and maintaining good conditioned interior space especially in a very large area. In general, duct system is normally used for distributing conditioned air to ensure uniform comfortable temperature distribution, good air movement and direction as well as acceptable humidity level. Therefore it is very important to be more concerned on duct system since if the system fails due to any reasons then the whole air conditioning system will not properly function, i.e. comfortable conditions can not be obtained.

At present, designing the duct system is not purely scientific but it is also a work of art. Different engineers will design different duct systems for the same conditioned space, i.e. different duct layouts, duct sizes, fan capacities etc. This results in different duct construction costs. The question arises that which duct design procedure is the optimum one for the same conditioned space. To answer this question, a thorough study on duct design procedure is required. Tsai and Behl (6) gave the necessary requirements for suitable duct system in their paper as follow;

1. The fan must operate at optimum system pressure.
2. The ratio between the velocities in all sections of duct system must be optimal.
3. Pressure balancing must be obtained by changing duct sizes, not dampers or any devices.

All four traditional duct design procedures, i.e. equal friction method, static regain method, velocity reduction method, and constant velocity method, cannot cover all of the requirements stated above. The equal friction, velocity reduction, and constant velocity method require damper to adjust air flow rate in each branch of duct system to obtain correct air flow rates. The static regain method intends to maintain static pressure at practically a constant value through duct system. This can be obtained from velocity reduction at the end of each duct section. Therefore the method is suitable for supply air duct system only. Moreover, the static regain factor, R, is unpredictable (4). In fact, ASHRAE guide started from 1985 to present no longer recommend any value for R (4).

In 1988, Tsal, Behls and Mangel (2,3) proposed a so-called T-Method duct design which covers all the requirements mentioned above. The concept is based on minimizing the objective function, i.e. the life cycle cost of the system, at each step of the calculations. Procedure for this method consists of system condensing, fan selection and system expansion. However, in their formulation, the only energy loss concerned is through fan. In fact, there are other energy losses such as energy loss due to heat transfer through duct wall, losses due to air leakage from the system etc. Moreover, they concentrated only on round duct system and used the same material and labour cost for all duct sizes. Practically, these are not true, especially in Thailand, since the duct construction cost is varied according to duct sizes. Apart from that, a rectangular duct is easier to fabricate at site than a round duct.

## 2. Modified T-Method Duct Design

The objective of T-Method duct design is to find the proper size of duct and proper selection of fan for the required air distribution system in order to minimize the system life cycle cost. The construction cost includes investment cost, tax, insurance, and salvage values. The operating cost includes electrical energy cost, maintenance cost, operating labour cost, income tax, and cost escalation. Therefore the purpose of this design procedure is to compare system cost for different fan total pressure. Only major costs such as investment cost, energy cost, time period, escalation rate, and interest rate are used for optimization. These parameters are therefore included in the objective function. Other costs are considered to be constant.

General constraints for duct design procedure are as follow;

1. Balancing of flow at any duct junction (Kirchoff's first law).
2. Total pressure loss in each path must be equal to the fan total pressure, i.e. pressure balancing (Kirchoff's second law).
3. The dimension of duct shall be rounded to the near nominal upper or lower duct sizes.
4. There is an acoustic or particles conveyance limitation.
5. Pre-selection of duct size is allowed due to installation space requirement.
6. Construction restrictions due to architectural space limitation which may restrict duct sizes.
7. Limitation on selection of air handling equipment which are manufactured by industry.

In this research, the T-Method duct design is modified to include the energy loss due to heat transfer through duct wall, and the variation of duct construction cost as well as rectangular duct formation. The objective function or the life cycle cost is

$$E = E_p(PWEF) + E_s \tag{2.1}$$

where E = Life cycle cost of duct system, baht

$E_P$ = First year electrical energy cost, baht

PWEF = Present worth escalation factor, dimensionless

$$= \frac{[(1+AER)/(1+AIR)]^a - 1}{1-[(1+AIR)/(1+AER)]} \tag{2.2}$$

AER = Annual electrical escalation rate, decimal

AIR = Annual interest rate, decimal

a = Amortization period, year

$E_s$ = Material and labour cost for duct construction, baht

First year electrical energy cost, $E_P$, is modified to include electrical cost due to heat loss through duct wall apart from electrical energy cost for fan as follow;

$$E_p = E_{fan} + E_{loss} \tag{2.3}$$

$E_{fan}$ = First year electrical energy cost for fan, baht

$$= Q_{fan} \frac{(E_c)Y + E_d}{10^3 \eta_f \eta_e} (P_{fan}) \tag{2.4}$$

where $Q_{fan}$ = Air flow rate, $m^3/s$

$E_c$ = Electrical unit cost, baht/kW-hr

Y = Total system operating time in one year, hr/year

$E_d$ = Energy demand charge, baht/kW

$P_{fan}$ = Fan total pressure, Pa

$\eta_f$ = Fan total efficiency, dimensionless

$\eta_e$ = Motor-drive efficiency, dimensionless

$E_{loss}$ = Electrical energy cost due to heat loss through duct wall, baht

$$= \frac{2U(H+W)L[E_cY+E_d]}{10^3 \eta_t} \left[ t_a - \frac{t_e + t_1}{2} \right] \tag{2.5}$$

where U = Total heat transfer coefficient through duct wall, watt/$m^2$°C

H = Duct height, m

W = Duct width, m

L = Duct length, m

$\eta_t$ = Total efficiency of air duct system, decimal

$t_a$ = Average air temperature around duct, Celsius

$t_e$ = Average cooled air temperature at the duct entrance, Celsius

$t_1$ = Average cooled air temperature at the duct exit, Celsius

$$= \frac{t_e(y-1)+2t_a}{(y+1)} \qquad (2.6)$$

$$y = \frac{1005Q\rho}{U(H+W)L} \qquad (2.7)$$

where Q = Air flow rate in duct, $m^3/s$

$\rho$ = Air density, $kg/m^3$

The duct construction cost is modified to take into account the variation of cost due to duct size as follow;

$$E_S = 2\sum_{i=1}^{n} S_{ri}(H_i+W_i)L_i \qquad (2.8)$$

where $S_r$ = Duct construction cost according to duct size, baht/$m^2$

Substituting eq. (2.2-2.8) in eq. (2.1), we have

$$E = Z_1P_{fan}+2\sum_{i=1}^{n} S_{ri}(H_i+W_i)L_i+ 2Z_2\sum_{i=1}^{n}(H_i+W_i)\left[t_a - \frac{t_{ei}+t_{1i}}{2}\right]L_i \qquad (2.9)$$

where $Z_1$ is the intermediate function which has a constant value for all duct sections in the same duct system while $Z_2$ is not a constant value for all duct sections. $Z_1$ and $Z_2$ are defined as follow;

$$Z_1 = \frac{Q_{fan}[E_cY+E_d](PWEF)}{10^3\eta_e\eta f} \qquad (2.10)$$

$$Z_2 = \frac{U[E_cY+E_d](PWEF)}{10^3\eta_t} \qquad (2.11)$$

Next step is to simplify eq. (2.9) by considering each duct section

$$E_i = Z_1\Delta P_i+2S_{ri}(H_i+W_i)L_i +2Z_2(H_i+W_i)\left[t_a - \frac{t_{ei}+t_{1i}}{2}\right]L_i \qquad (2.12)$$

let $$\Delta t_i = \left[t_a - \frac{t_{ei}+t_{1i}}{2}\right]$$

Rearranging eq. (2.12), we have

$$E_i = Z_i\Delta P_i+2(S_{ri}+Z_2t_i)(H_i+W_i)L_i \qquad (2.13)$$

where $\Delta P$ can be calculated from Darcy-Weibach equation for rectangular duct as follow;

$$\Delta P = \left[\frac{fL(H+W)}{2HW}+\sum C\right]\frac{V^2\rho}{2g_c} \qquad (2.14)$$

where f = Friction factor, dimensionless

C = Local loss coefficient, dimensionless

$g_c$ = Unit conversion factor, 1.0 kg-m / N-$s^2$

V = Average air velocity in duct, m/s

= Q/(H*W) for rectangular duct

Therefore

$$\Delta P = \left[\frac{fL(H+W)}{2HW}+\sum C\right]\frac{Q^2\rho}{2g_cH^2W^2} \qquad (2.15)$$

Introducing the aspect ratio, r, for rectangular duct;

$$r = \frac{H}{W} \qquad (2.16)$$

We now consider several restrictions at the installation space as follow;

Case 1 : For no space restriction, the aspect ratio equals to 1 or H = W shall be used since this will give the minimum $E_{loss}$ and $E_s$ (7).

Case 2 : When there are restrictions on height or width of the duct at the installation space.

Case 3 : When there are restrictions on aspect ratio due to acoustic and requirement on no excessive heat loss through duct wall.

Case 4 : When exact duct size must be used.

From these four cases, one can see that case 3 also covers case 1 in case that r = 1. Therefore for simplicity we will consider these two cases together, i.e. the case when the aspect ratio is fixed.

Eq. (2.15) is then rearranged according to cases mentioned above as follow ;

2.1 When aspect ratio is fixed

$$\Delta P = \left[\frac{fL(r+1)}{2r^3}+\sum\frac{C}{r^2}W\right]\frac{Q^2\rho}{2g_cW^5} \qquad (2.17)$$

Let $$\mu_1 = \frac{fL(r+1)}{2r^3}+\frac{\sum C}{r^2}W \qquad (2.18)$$

Then from eq. (2.17)

$$W = (\mu_1\rho)^{0.2}Q^{0.4}(2g_c\Delta P)^{-0.2} \qquad (2.19)$$

2.2 When height or width is limited

$$\Delta P = \left[\frac{fL}{2W}+\frac{fL}{2H}+\sum C\right]\frac{Q^2\rho}{2g_cH^2W^2} \qquad (2.20)$$

If H is constant then

$$\Delta P = \left[\frac{fL}{2}+(\frac{fL}{2H}+\sum C)W\right]\frac{Q^2\rho}{2g_cH^2W^3} \qquad (2.21)$$

Let $$\mu_2 = \frac{fL}{2}+(\frac{fL}{2H}+\sum C)W \qquad (2.22)$$

Then $W = (\mu_2 \rho)^{1/3} Q^{2/3} H^{-2/3} (2g_c \Delta P)^{-1/3}$ (2.23)

If W is constant then

$$\Delta P = \left[\frac{fL}{2} + \left(\frac{fL}{2W} + \sum C\right)H\right]\frac{Q^2 \rho}{2g_c H^3 W^2} \quad (2.24)$$

Let $$\mu_3 = \frac{fL}{2} + \left(\frac{fL}{2W} + \sum C\right)H \quad (2.25)$$

Then $H = (\mu_3 \rho)^{1/3} Q^{2/3} W^{-2/3} (2g_c \Delta P)^{-1/3}$ (2.26)

2.3 When H and W are given

For this case all parameters in eq. (2.15) are constant and cannot be changed.

The objective function for each duct section is then simplified according to case 2.1-2.3 mentioned above as follow;

1. For given aspect ratio or r = 1

$$E_1 = Z_1 \Delta P_1 + 2(r_1+1)(S_{r1} + Z_2 \Delta t_1) \times (\mu_1 \rho)^{0.2} Q_1^{0.4} (2g_c \Delta P_1)^{-0.2} L_1 \quad (2.27)$$

$$\text{let } K_1 = 2(r_1+1)(S_{r1} + Z_2 \Delta t_1)(\mu_1 \rho)^{0.2} Q_1^{0.4} (2g_c)^{-0.2} L_1 \quad (2.28)$$

$$\text{then } E_1 = Z_1 \Delta P_1 + K_1 \Delta P_1^{-0.2} \quad (2.29)$$

2. For height is limited

$$E_2 = Z_1 \Delta P_2 + 2(S_{r1} + Z_2 t_2)[H_2 + (\mu_2 \rho)^{1/3} Q_2^{2/3} H_2^{-2/3} (2g_c \Delta P_2^{-1/3}] L_2 \quad (2.30)$$

$$\text{let } K_2 = 2(S_{r2} + Z_2 \Delta t_2)(\mu_2 \rho)^{1/3} Q_2^{2/3} H_2^{-2/3} (2g_c)^{-1/3} L_2 \quad (2.31)$$

$$\text{then } E_2 = Z_1 \Delta P_2 + K_2 \Delta P_2^{-1/3} + 2(S_{r2} + Z_2 \Delta t_2) H_2 L_2 \quad (2.32)$$

3. For width is limited

$$E_3 = Z_1 \Delta P_3 + 2(S_{r3} + Z_2 \Delta t_3)[W_3 + (\mu_2 \rho)^{1/3} \times Q_3^{2/3} W_2^{-2/3} (2g_c \Delta P_3)^{-1/3}] L_3 \quad (2.33)$$

$$\text{let } K_3 = 2(S_{r3} + Z_2 \Delta t_3)(\mu_2 \rho)^{1/3} Q_3^{2/3} W_3^{-2/3} (2g_c)^{-1/3} L_3 \quad (2.34)$$

$$\text{then } E_3 = Z_1 \Delta P_3 + K_3 \Delta P_3^{-1/3} + 2(S_{r3} + Z_2 \Delta t_3) W_3 L_3 \quad (2.35)$$

where $K_1$, $K_2$, and $K_3$ are duct characteristics.

The general form of objective functions in eq. (2.29), (2.32), and (2.35) can be written as follow;

$$E_n = Z_1 \Delta P_n + K_n \Delta P_n^{-\lambda} + X_n \quad (2.36)$$

where $X_a$ is a parameter that has no effect on optimizing duct system.

Eq. (2.36) is then minimized for each duct section for system condensing procedure. Two duct sections connected in a series will be replaced by an imaginary section which have the duct characteristic as follow ;

$$K_{i-j} = (K_i^{1/(\lambda-1)} + K_j^{1/(\lambda-1)})^{\lambda+1} \quad (2.37)$$

For two duct sections connected in parallel, the replacing imaginary section will have the duct characteristic as follow;

$$K_{i-j} = K_i + K_j \quad (2.38)$$

If n duct sections connected in parallel, the relation between n duct section and the replacing imaginary section is

$$K_{i-n} = \sum_{i=1}^{n} K_i \quad (2.39)$$

Condensing tee section which consists of two duct sections connected in parallel and then connected with another duct section in series, the duct characteristic of the imaginary section is

$$K_{i-k} = [(K_i + K_j)^{1/(\lambda+1)} + K_k^{1/(\lambda+1)}]^{\lambda+1} \quad (2.40)$$

By performing system condensing from the ending point back to the starting point of duct system will result in one imaginary duct section which has the following objective function;

$$E = Z_i P_{fan} + K_{1-n} P_{fan}^{-\lambda} + X_{1-n} \quad (2.41)$$

This objective function is then minimized with respect to $P_{fan}$ to get the optimum fan pressure as follow;

$$P_{fan}^{opt} = \left(\frac{\lambda K_{1-n}}{Z_1}\right)^{1/(\lambda+1)} + \Delta Pz_{max} \quad (2.42)$$

where $\Delta Pz_{max}$ is the pressure loss due to air flow through devices installed inside duct system such as air filter etc.

This imaginary section is then expanded in order to convert back to a new optimum duct system by keeping the suitable pressure for parallel ducts connection and ducts connected in series.

For duct expansion in series

$$\Delta P_{up} = \left(\frac{K_{up}}{K_{root}}\right)^{1/(\lambda+1)} \Delta P_{root} \quad (2.43)$$

$$\Delta P_{down} = \Delta P_{root} - \Delta P_{up} \quad (2.44)$$

where the subscript *up* means upstream duct section, *root* means imaginary duct section, and *down* means downstream duct section.

For duct expansion in parallel, the pressure loss in each section must be equal.

$$\Delta P_{root} = \Delta P_{br1} = \Delta P_{br2} = \Delta P_{br3} = \ldots\ldots = P_{brn} \quad (2.45)$$

A computer program using FORTRAN language is written to perform the calculation according to the method outlined above. The results are then compared with those from equal friction method, static regain method, and conventional T-Method duct design as shown in the following section.

## 3. Result Analysis and Comparison

The duct system used for this analysis is shown in Fig. 1 in appendix I. The system consists of supply air duct, and return air duct. All duct sections are identified by their number. The following data are used in the analysis ;

1. Annual escalation rate = 4.0 %
2. Annual interest rate = 13.5 %
3. Amortization period = 10 yrs.
4. Unit energy cost = 1.10 baht/kW-hr.
5. Energy demand charge = 237.0 baht/kW-hr.
6. System operating time = 4,400 hrs/yr.
7. Motor drive efficiency = 90 %
8. Fan total efficiency = 75 %
9. Total efficiency of air duct system = 50 %
10. Heat transfer coefficient through wall = 1.412 watt/sq.m
11. Average air temperature around duct = 25°C
12. Average cooled air temperature at the duct entrance = 15°C
13. Material cost for duct construction

13.1 For duct size smaller than or equal to 30 cm. used galvanized steel sheet no. 26 cost = 85 baht/sq. m

13.2 For duct size greater than 30 cm. and less than or equal to 75 cm. used galvanized steel sheet no. 24 cost = 100 baht/sq. m

13.3 For duct size greater than 75 cm. and less than or equal to 135 cm. used galvanized steel sheet no. 22 cost = 130 baht/sq. m

13.4 For duct size greater than 135 cm. used galvanized steel sheet no. 20 cost = 150 baht/sq. m

14. Insulation cost = 80 baht/sq. m
15. Labor cost and other overhead = 110 baht/sq. m

In this analysis, the duct size on section no. 6, 17, 28, and 40 is pre-determined for velocity limitation in order to verify the flexibility of the method presented here.

Other parameters for other duct design methods are as follow; For equal friction method, the frictional resistance is set at 0.85 pa/m. For static regain method, the upstream velocity is selected at 11.25 m/s., the size of main duct is 80x80 cm. and the static regain factor is 0.75. For conventional T-Method duct design, the air temperature is set at 15°C for both inlet and around duct for no heat loss purpose and the material cost is set at 120 baht/sq. m for all sizes of duct. The resulting duct system layouts from each method are shown in Fig. 2-5 in appendix I. The analysis of the results is presented as follow;

### 3.1 Result analysis for air flow distribution

Results from different methods are shown in table 1 to 4 in appendix I. Pressure balancing is most satisfied through the modified T-Method duct design when compared with those from other methods.

### 3.2 Result analysis for system total cost

In this analysis, system cost is divided into 3 parts according to eq. 2.9. The first part is electrical cost for fan within 10 years which is converted into present value. The second part is material and labor cost for duct construction. The third part is present value of electrical cost due to heat loss through duct wall within 10 years. The result is shown in Table 1. It can be seen that the new modified T-Method duct design provides the minimum life cycle cost when compared with those from other design methods.

Table 1 Cost comparison (All costs in Baht)

| Design Method | Cost for Part I | Cost for Part II | Cost for Part III | Total Cost |
|---|---|---|---|---|
| Equal friction method | 93,175.50 | 103,813.80 | 198,120.56 | 395,109.86 |
| Static regain method | 124,582.00 | 103,593.60 | 198,175.57 | 426,351.17 |
| Conventional T-Method | 75,676.36 | 119,056.60 | 204,419.68 | 399,152.64 |
| Modified T-Method | 86,859.63 | 103,497.10 | 160,804.63 | 351,161.36 |

## 4. Summary and Conclusion

The modified T-Method duct design is presented. This modified method includes the electrical cost due to heat loss through duct wall which has been neglected in the conventional T-Method. The result shows the significant effect of this cost to the system life cycle cost. Moreover, the variation in material cost is also included to represent more realistic cost for duct construction. Pressure balancing is also obtainable in a better manner as well as pre-determined velocity in any duct section is also possible for noise requirement.

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APPENDIX I

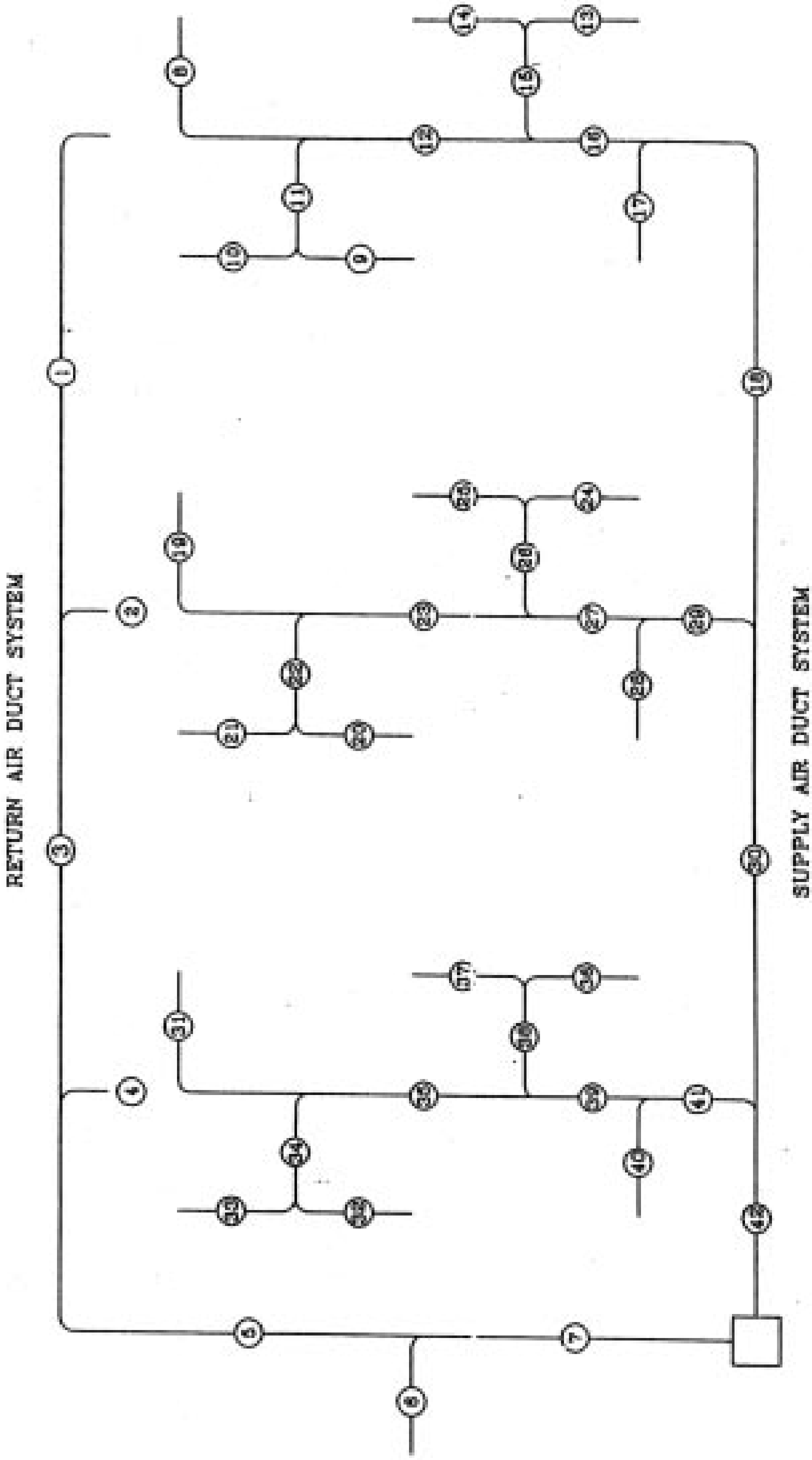


**Figure 1. Duct System Layout**

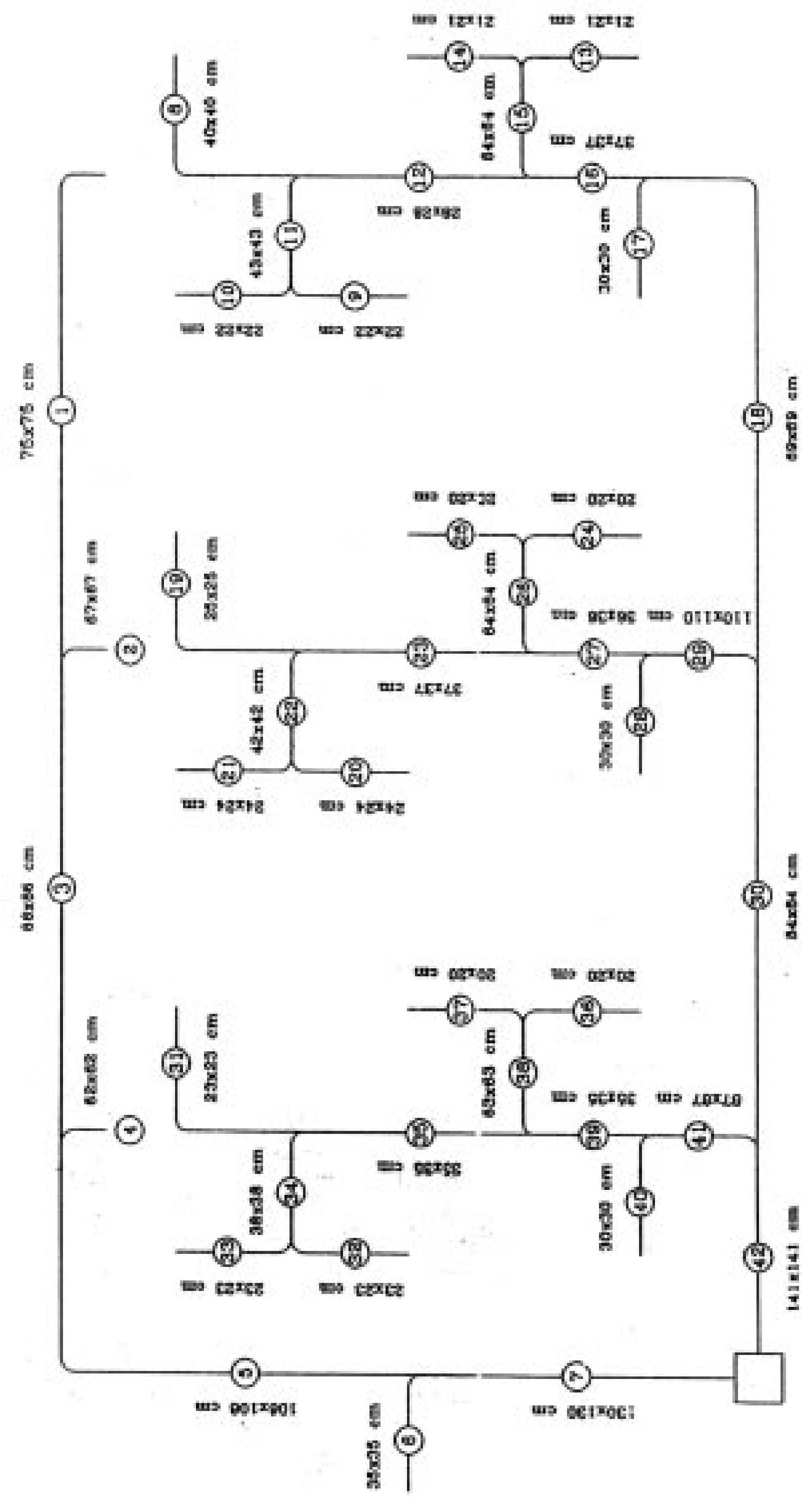

**Figure 2. Duct Size Calculated by using Conventional T-Method**

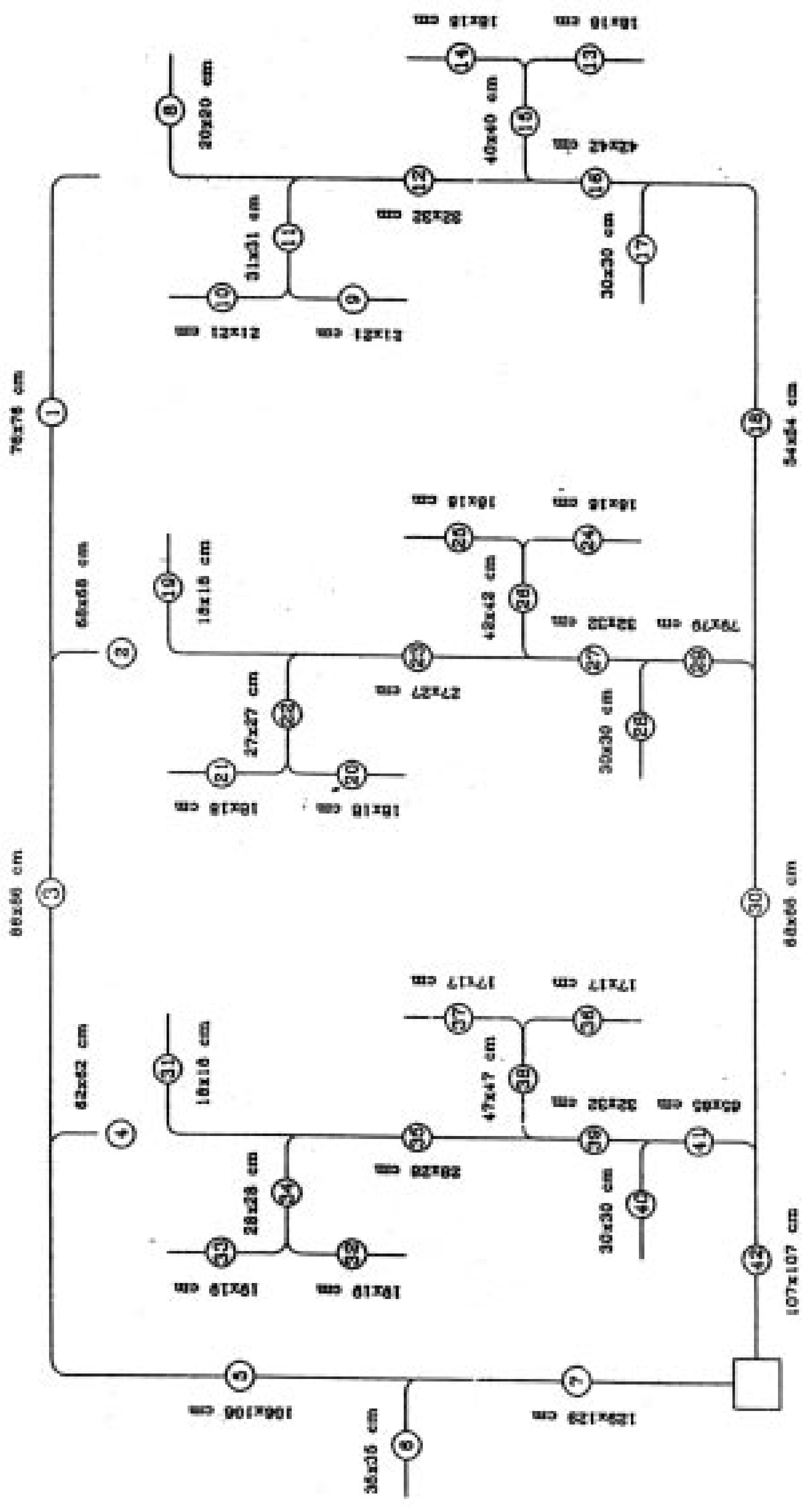

**Figure 3. Duct Size Calculated by using Modified T-Method**

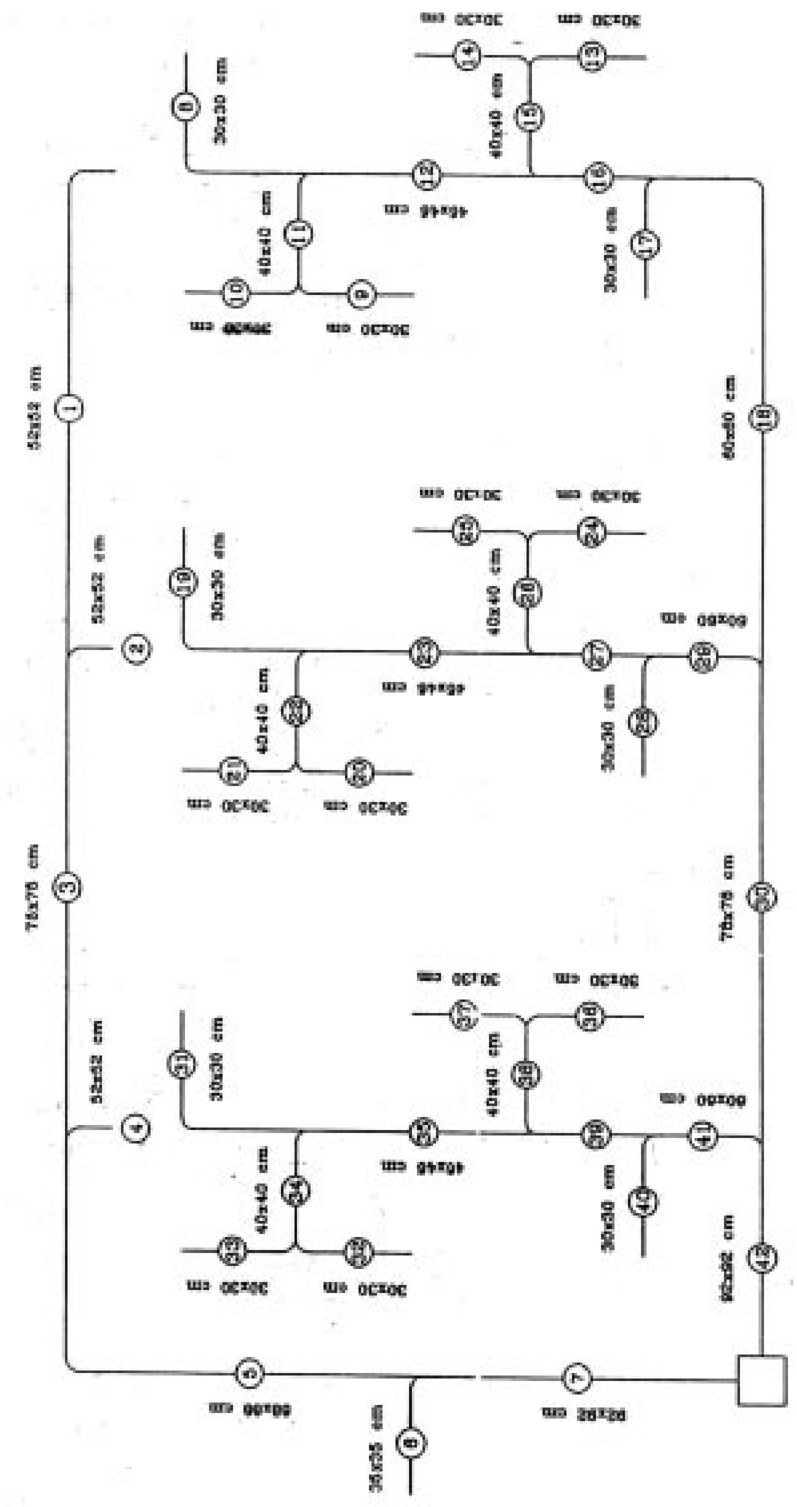

**Figure 4. Duct Size Calculated by using Equal Friction Method**

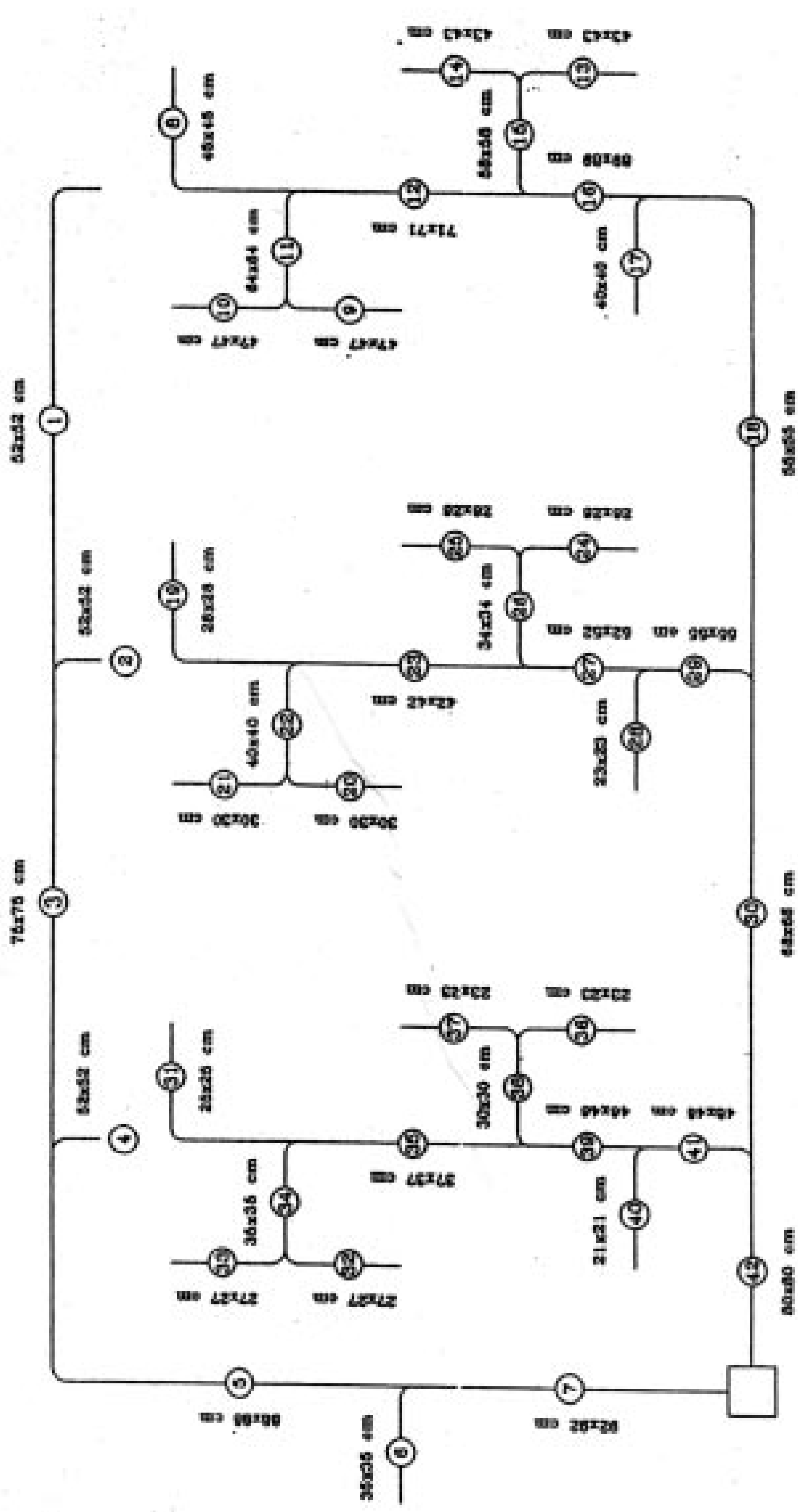

**Figure 5. Duct Size Calculated by using Static Regain Method**

LOOP = 1 ITERATION = 31

| PRESSURE LOSS | |
|---|---|
| Total Pressure Loss in Path<br>Pa | Excess Pressure Loss in Path<br>Pa |
| DPp | DPex |
| 49.99 | -.22 |
| 49.70 | .08 |
| 38.16 | .00 |
| 49.94 | -.17 |
| 25.50 | .00 |
| 25.13 | 24.65 |
| 6.70 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 174.91 | .00 |
| 157.58 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 167.88 | .00 |
| 134.25 | .00 |
| 154.00 | 44.04 |
| 123.74 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 151.26 | .00 |
| 116.65 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 144.36 | .00 |
| 71.42 | .00 |
| 129.07 | 68.96 |
| 109.25 | .00 |
| 86.81 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 158.72 | .00 |
| 129.59 | .00 |
| 198.03 | .00 |
| 198.03 | .00 |
| 154.75 | .00 |
| 92.08 | .00 |
| 110.83 | 87.20 |
| 87.04 | .00 |
| 63.76 | .00 |

**Table 1. Pressure loss for duct system calculated by using Modified T-Method**

LOOP = 1. ITERATION =113

| PRESSURE LOSS | |
|---|---|
| Total Pressure Loss in Path Pa | Excess Pressure Loss in Path Pa |
| DPp | DPex |
| 49.43 | .00 |
| 49.43 | .00 |
| 37.62 | .00 |
| 49.43 | .00 |
| 25.14 | .00 |
| 24.86 | 24.57 |
| 6.53 | .00 |
| 82.35 | 27.88 |
| 91.92 | 18.31 |
| 91.92 | 18.31 |
| 80.75 | .00 |
| 71.35 | .00 |
| 101.21 | 9.02 |
| 101.21 | 9.02 |
| 88.48 | .00 |
| 69.87 | .00 |
| 93.04 | 17.19 |
| 74.48 | .00 |
| 110.43 | -.18 |
| 124.80 | -14.57 |
| 124.80 | -14.57 |
| 107.11 | .00 |
| 76.00 | .00 |
| 49.43 | 60.80 |
| 49.43 | 60.80 |
| 35.18 | .00 |
| 11.94 | .00 |
| 86.56 | 23.67 |
| 69.13 | .00 |
| 62.06 | .00 |
| 109.34 | .90 |
| 115.85 | -5.62 |
| 115.85 | -5.62 |
| 96.78 | .00 |
| 72.54 | .00 |
| 68.50 | 41.73 |
| 68.50 | 41.73 |
| 51.82 | .00 |
| 23.27 | .00 |
| 80.04 | 30.19 |
| 62.03 | .00 |
| 54.54 | .00 |

**Table 2. Pressure loss for duct system calculated by using Conventional T-Method**

LOOP = 4 ITERATION = 1

| PRESSURE LOSS | |
|---|---|
| Total Pressure Loss in Path<br>Pa | Excess Pressure Loss in Path<br>Pa |
| DPp | DPex |
| 137.42 | .00 |
| 131.17 | 6.25 |
| 81.80 | .00 |
| 111.99 | 25.43 |
| 63.96 | .00 |
| 44.92 | 92.50 |
| 27.31 | .00 |
| 117.97 | 14.14 |
| 124.64 | 7.47 |
| 124.64 | 7.47 |
| 118.27 | .00 |
| 110.57 | .00 |
| 124.72 | 7.39 |
| 124.72 | 7.39 |
| 118.34 | .00 |
| 107.33 | .00 |
| 122.80 | 9.32 |
| 105.39 | .00 |
| 125.37 | 6.75 |
| 132.04 | .08 |
| 132.04 | .08 |
| 125.66 | .00 |
| 117.96 | .00 |
| 132.11 | .00 |
| 132.11 | .00 |
| 125.74 | .00 |
| 114.73 | .00 |
| 130.19 | 1.92 |
| 112.78 | .00 |
| 81.82 | .00 |
| 120.90 | 11.22 |
| 127.57 | 4.54 |
| 127.57 | 4.54 |
| 121.19 | .00 |
| 113.49 | .00 |
| 127.65 | 4.47 |
| 127.65 | 4.47 |
| 121.27 | .00 |
| 110.26 | .00 |
| 125.72 | 6.39 |
| 108.31 | .00 |
| 75.62 | .00 |

**Table 3. Pressure loss for duct system calculated by using Equal Friction Method**

LOOP = 4 ITERATION = 1

| PRESSURE LOSS | |
|---|---|
| Total Pressure Loss in Path Pa | Excess Pressure Loss in Path Pa |
| DPp | DPex |
| 137.42 | .00 |
| 131.17 | 6.25 |
| 81.80 | .00 |
| 111.99 | 25.43 |
| 63.96 | .00 |
| 44.92 | 92.50 |
| 27.31 | .00 |
| 141.83 | 81.13 |
| 142.54 | 80.42 |
| 142.54 | 80.42 |
| 141.64 | .00 |
| 140.63 | .00 |
| 143.36 | 79.60 |
| 143.36 | 79.60 |
| 142.02 | .00 |
| 140.17 | .00 |
| 198.75 | 24.21 |
| 142.00 | .00 |
| 173.77 | 49.20 |
| 176.76 | 46.20 |
| 176.76 | 46.20 |
| 170.38 | .00 |
| 163.52 | .00 |
| 187.14 | 35.83 |
| 187.14 | 35.83 |
| 174.78 | .00 |
| 157.80 | .00 |
| 157.39 | 65.57 |
| 155.32 | .00 |
| 108.19 | .00 |
| 201.20 | 21.76 |
| 207.07 | 15.89 |
| 207.07 | 15.89 |
| 196.33 | .00 |
| 183.89 | .00 |
| 222.96 | .00 |
| 222.96 | .00 |
| 201.87 | .00 |
| 173.07 | .00 |
| 192.03 | 30.93 |
| 168.89 | .00 |
| 95.60 | .00 |

**Table 4. Pressure loss for duct system calculated by using Static Regain Method**