

Application Study of a Single House Horizontal Heating System

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Abstract: It is imperative to get new heating systems into the market and implement rate structures with heat meters for the purpose of energy conservation and environmental protection. Based on analysis of current heating technology, this paper analyzes the different forms of heating systems suited for single household metering. We introduce especially the single house horizontal spanning system and show how to select the heat flow rate of the radiator. We also study the distribution rule of the heat intermedium of horizontal heating system. To simplify the workload of engineering process and make the design more accurate, a new method for calculating the average temperature of the intermedium and the heat flow rate of this heating system is put forward. Comparison is also made between the system in question and the heating system in series. A few important questions are raised and discussed, such as the computation of combining different forms of radiators, the verification of the pipe radiation, the end of the radiator without spanning pipe, and the selection of the pipe diameter. At the same time, we study the influence of the horizontal heating system on the whole heating network, describe the characteristics of a single household horizontal heating system and the importance of its hydraulic computation, and analyze the influence of the gravitational head to this heating system. We also study the hydraulic condition of the single house horizontal system and the relationship of each party under the adjustment.

In addition, the operation of single household horizontal heating system is verified in a real project, and its reliability is testified. This paper provides a method for further research on related issues of a single household metering heating system and is valuable for design, operation and management.

Key words: Heating system; Single household horizontal; Intermedium temperature; Heat flow rate of radiator; Gravitational head

1. INTRODUCTION OF SINGLE HOUSE HORIZONTAL SPANNING SYSTEM (HSS)

In the daily design, the heating system is often designed by unit. Each unit has one heating entry which are all connected to the main heating line. The layout of the pipe in house has the following forms:

- 1) Radiate with horizontal double line
- 2) Parallel with horizontal double line
- 3) Spanning with horizontal single line(as Fig1)
- 4) Radiate with low temperature floor

Among the above, form 3 are derived from Single Line in Series (hereinafter as SLS), and inherit the advantages of simple system, less material and fittings. But it also overcomes the disadvantage of the latter which cannot adjust the heating flow. Comparatively form 1 and 2 are complicated and has more difficulties to install and hide the pipes. On the other hand, the resistance of SLS system is bigger. If the duration of heating is short, even the ends of the radiators are cold, the heating is stopped. Setup of the spanning line will increase the temperature of the radiator ends and improve the heating effect. Therefore, the HSS

system are adopted by many designers in their projects and become one of the main heating systems.

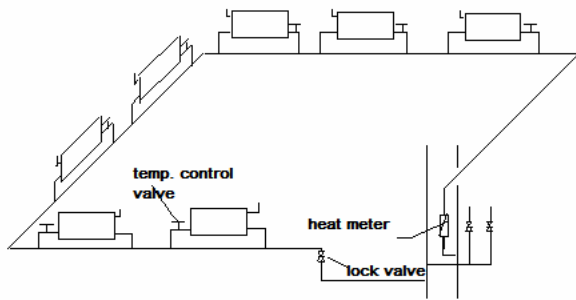


Fig. 1 Format of single house horizontal system

2. SELECTION OF HEAT FLOW FACTOR

It is important to select the heat flow factor when studying the HSS system. According to Ref [1], we can get the characteristic diagram of convective radiator with different heating temperature and flow, see Fig.2

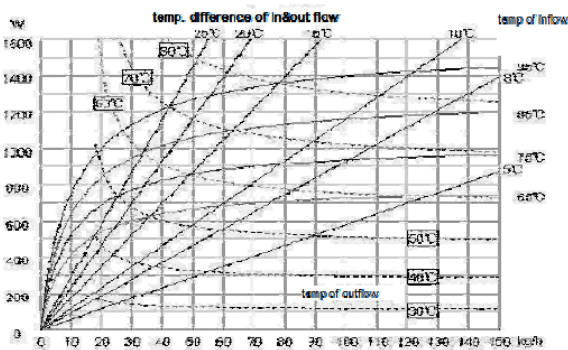


Fig. 2 Characteristic diagram of convective Radiator

From the Fig.2, the radiating capacity is always sensitive to the water temperature, but has reverse effect with the heat flow. From the respect of control, we can see that less heat flow, better control.

Therefore the following conclusion can be got:

Within certain scope, the heat flow has less affect on radiating capacity than the heating temperature. In other words, when the heat flow and heating temperature are changed in opposite direction, the radiating capacity lies on the change

of heating temperature^[2].

The large difference in temperature (20~25°C for instance) of the inflow and outflow represents the better control ability of radiators; on the contrary, the small difference (20~25°C for instance) means the worse control ability. If diffiulce rate is 70% and inflow rate is 30%, the design flow through the radiator is lesser and the design difference in temperature will be 15—25°C. In this way, the control ability of the single line system is equal to the double line system. Economic factor is another reason to set diffiulce rate as 70%. By calculating the heating system in a house with six rooms, Ref^[5] get the data in table 1:

Tab.1 Compare table of diffiulce rate and radiating area

diffiulce rate	90%	80%	70%	50%	30%	10%
inflow rate	10%	20%	30%	50%	70%	90%
no. of units	120	89	81	76	74	74

From table 1, if the diffiulce rate is set as 80% or more, the control ability of radiator is even better, however, it is not an economic selection because more radiators have to be used. If the diffiulce rate is set as too small (10—50% for example), though the control ability becomes worse, the number of radiators cannot be reduced. Therefore, considering the factors of control ability and economy, it is reasonable to select 70% as diffiulce rate and 30% as inflow rate. In my study, the inflow rate is set as 70%.

3. THERMODYNAMIC FORMULA OF HSS SYSTEM

HSS system has the following thermodynamic formula:

$$Q1=Q2=Q3$$

Q1: heat load in room, W;

Q2: radiating capacity, W;

Q3: heating capacity of heat intermedium, W;

Thereinto

$$Q_2 = KF(t_{pj} - t_n)$$

$$Q_3 = CG(t_g - t_h)$$

- K: diathermanous factor, $W/m^2 \cdot ^\circ C$;
- F: heat radiating area, m^2 ;
- t_{pj} : average tmp. of heat intermedium, $^\circ C$;
- t_n : design temperature, $^\circ C$;
- C: specific heat of heat intermedium, $J/kg \cdot ^\circ C$;
- G: flow of heat intermedium, kg/h ;
- t_g : inflow temperature of heat intermedium, $^\circ C$;
- t_h : outflow temperature of heat intermedium, $^\circ C$;

The above formulas express an ideal situation under a reliable condition and wouldn't consider the heat lose on the way. Then the heating capacity of the heat intermedium is equal to the heat load of the room in question, and equal to the radiating capacity of the radiators.

4. DISTRIBUTION RULE OF HEAT INTERMEDIUM OF HSS SYSTEM

In previous engineering design, the radiating capacity of the SLS system is calculated under the condition that each radiator unit has the same heat load. When large radiators appear, they are normally calculated by splitting into two units or more. Similarly, we can calculate the radiating capacity of the HSS system in this way. On the assumption that the heat load of each radiator unit is $Q(w)$.

4.1 Distribution formula of HSS system by Induction

If the room temperature t_n is invariable, the radiating capacity has only related with the average temperature t_{pj} of heat intermedium, therefore we start the distribution rule by inducing heat intermedium temperature.

Take single unit radiator for instance (Fig. 3):

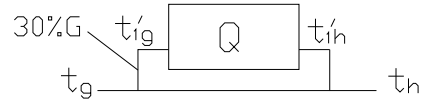


Fig 3 Diagram of single set of radiator

$$Q=CG \Delta t, \quad C=4.2kj/kg \cdot ^\circ C$$

$$\text{So } G' = \frac{3.6Q}{4.2(t_g - t_h)} = \frac{0.86Q}{(t_g - t_h)} kg/h = G$$

Set inflow rate as 30% and diffulence rate as 70%

$$\Delta t'_1 = t'_{1g} - t'_{1h} = \frac{10}{3}(t_g - t_h)$$

$$t'_{1g} = t_g$$

$$t'_{1h} = t_g - \Delta t'_1 = t_g - \frac{10}{3}(t_g - t_h)$$

$$\text{Checkout } t_h = 0.7t_g + 0.3[t_g - \frac{10}{3}(t_g - t_h)]$$

$$= t_g - t_g + t_h = t_h$$

Take two units for instance (Fig.4):

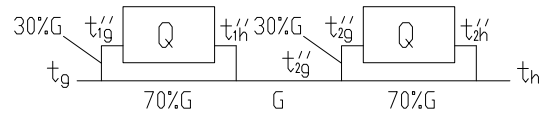


Fig 4 Diagram of two sets of radiators

$$\text{Because } G'' = \frac{1.72Q}{(t_g - t_h)} kg/h = 2G$$

$$\Delta t''_1 = t_{1g}'' - t_{1h}'' = \frac{10}{3} \cdot \frac{1}{2} \cdot (t_g - t_h) = \frac{5}{3}(t_g - t_h)$$

$$t_{1g}'' = t_g$$

$$t_{1h}'' = t_{1g}'' - \Delta t''_1 = t_g - \Delta t''_1 = t_g - \frac{5}{3}(t_g - t_h)$$

$$t_{2g}'' = 0.7t_g + 0.3t_{1h}'' = 0.7t_g + 0.3[t_g - \frac{5}{3}(t_g - t_h)]$$

$$= 0.7t_g + 0.3t_g - 0.5t_g + 0.5t_h = 0.5t_g + 0.5t_h$$

$$= \frac{1}{2}(t_g + t_h) = t_g - \frac{1}{2}(t_g + t_h)$$

$$\text{Because } \Delta t_2'' = \Delta t_1'' = \frac{5}{3}(t_g - t_h)$$

$$\begin{aligned}
 t_{2h}'' &= t_{2g}'' - \frac{1}{2}(t_g - t_h) \\
 &= t_g - \frac{1}{2}(t_g - t_h) - \frac{5}{3}(t_g - t_h) = t_g - \frac{3+10}{6}(t_g - t_h) \\
 &= t_g - \frac{3+10}{6}(t_g - t_h) = t_g - \frac{13}{6}(t_g - t_h)
 \end{aligned}$$

Checkout

$$\begin{aligned}
 t_h &= 0.7 \cdot 0.5(t_g - t_h) + 0.3[t_g - \frac{13}{6}(t_g - t_h)] \\
 &= 0.35t_g + 0.35t_h + 0.3t_g - 0.05 \cdot 13t_g + 0.05 \cdot 13t_h \\
 &= t_h
 \end{aligned}$$

Take three units for instance (Fig.5):

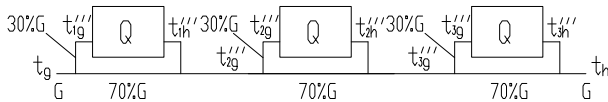


Fig. 5 Diagram of three sets of radiators

Because $G''' = \frac{2.58Q}{(t_g - t_h)} kg/h = 3G$

$$\Delta t_1''' = t_{1g}''' - t_{1h}''' = \frac{10}{3} \cdot \frac{1}{3} \cdot (t_g - t_h) = \frac{10}{9}(t_g - t_h)$$

$$t_{1h}''' = t_{1g}''' - \Delta t_1''' = t_g - \Delta t_1''' = t_g - \frac{10}{9}(t_g - t_h)$$

$$\begin{aligned}
 t_{2g}''' &= 0.7t_g + 0.3t_{1h}''' = 0.7t_g + 0.3t_g - \frac{1}{3}(t_g - t_h) \\
 &= t_g - \frac{1}{3}(t_g - t_h)
 \end{aligned}$$

Because $\Delta t_2''' = \Delta t_1''' = \frac{10}{9}(t_g - t_h)$

Then

$$\begin{aligned}
 t_{2h}''' &= t_{2g}''' - \Delta t_2''' \\
 &= t_g - \frac{1}{2}(t_g - t_h) - \frac{10}{9}(t_g - t_h) = t_g - \frac{13}{9}(t_g - t_h)
 \end{aligned}$$

$$\begin{aligned}
 t_{3h}''' &= 0.7[t_g - \frac{1}{3}(t_g - t_h)] + 0.3[t_g - \frac{13}{9}(t_g - t_h)] \\
 &= 0.7t_g - \frac{0.7}{3}(t_g - t_h) + 0.3t_g - \frac{0.3 \times 13}{9}(t_g - t_h)
 \end{aligned}$$

$$= t_g - (\frac{7}{30} + \frac{13}{30})(t_g - t_h) = t_g - \frac{2}{3}(t_g - t_h)$$

Because $\Delta t_3''' = \Delta t_1''' = \frac{10}{9}(t_g - t_h)$

$$\begin{aligned}
 t_{3h}''' &= t_{3g}''' - \Delta t_3''' = t_g - \frac{2}{3}(t_g - t_h) - \frac{10}{9}(t_g - t_h) \\
 &= t_g - \frac{6+10}{9}(t_g - t_h) = t_g - \frac{16}{9}(t_g - t_h)
 \end{aligned}$$

Checkout

$$\begin{aligned}
 t_h &= 0.7[t_g - \frac{2}{3}(t_g - t_h)] + 0.3[t_g - \frac{16}{9}(t_g - t_h)] \\
 &= 0.7t_g - 0.7 \cdot \frac{2}{3}(t_g - t_h) + 0.7 \cdot \frac{2}{3}t_h + 0.3t_g - \frac{1.6}{3}t_g + \frac{1.6}{3}t_h \\
 &= t_g - t_g + t_h = t_h
 \end{aligned}$$

To Sum up the distribution rule of heat intermedium temperature, we can use n as total amount of the radiators, then the radiator unit a has the following formula:

$$G = \frac{0.86Q}{t_g - t_h}$$

$$G^{(n)} = nG$$

The difference in temperature of the flow before diffluence and confluence of each radiator unit is:

$$\Delta t_z^{(n)} = \frac{1}{n}(t_g - t_h)$$

Then difference in temperature of the inflow and outflow of heat intermedium in each unit is:

$$\Delta t^{(n)} = \frac{10}{3n}(t_g - t_h)$$

The inflow temperature of the first unit is same as the temperature of supplying the heat intermedium:

$$t_{1g}^{(n)} = t_g$$

The outflow temperature of the first unit is:

$$t_{1h}^{(n)} = t_{1g}^{(n)} - \Delta t = t_g - \frac{10}{3n}(t_g - t_h)$$

The inflow temperature of the second unit is equal to the temperature of the mixer of the outflow of the first unit and the heat intermedium in the spanning line:

$$\begin{aligned}
 t_{2g}^{(n)} &= 0.7t_g + 0.3[t_g - \frac{10}{3n}(t_g - t_h)] \\
 &= 0.7t_g + 0.3t_g - \frac{1}{n}(t_g - t_h) = t_g - \frac{1}{n}(t_g - t_h)
 \end{aligned}$$

The outflow temperature of the second unit is:

$$t_{2h}^{(n)} = t_{2g}^{(n)} - \Delta t = t_g - \frac{1}{n}(t_g - t_h) - \frac{10}{3n}(t_g - t_h)$$

$$= t_g - \frac{1 + \frac{10}{3}}{n}(t_g - t_h) = t_g - \frac{13}{3n}(t_g - t_h)$$

The inflow temperature of the unit a is equal to the temperature of the mixer of the outflow of the unit a+1 and the heat intermedium in the spanning line:

$$t_{ag}^{(n)} = t_g - \frac{(a-1)}{n}(t_g - t_h)$$

The outflow temperature of the unit a is:

$$t_{ah}^{(n)} = t_g - \frac{(a-1)}{n}(t_g - t_h) - \frac{10}{3}(t_g - t_h) = t_g - \frac{(a + \frac{10}{3} - 1)}{n}(t_g - t_h)$$

$$= t_g - \frac{(a + \frac{7}{3})}{n}(t_g - t_h)$$

4.2 Distribution formula of HSS system by mathematics Induction

The number of the radiators in the HSS system is n, and the outflow temperature of the unit a is

$$t_{ag}^{(n)} = t_g - \frac{(a-1)}{n}(t_g - t_h) \quad (F1)$$

$$t_{ah}^{(n)} = t_g - \frac{(a + \frac{7}{3})}{n}(t_g - t_h) \quad (F2)$$

Formula 1 and 2 are summed up by induction.

We now testify it by mathematics induction:

When a=1

$$t_{1g}^{(n)} = t_g - \frac{(1-1)}{n}(t_g - t_h) = t_g - 0 = t_g$$

$$t_{1h}^{(n)} = t_g - \frac{10}{3n}(t_g - t_h) = t_g - \frac{10}{3n}(t_g - t_h)$$

Then formula 1 and 2 are true

When a=2

$$t_{2g}^{(n)} = t_g - \frac{(2-1)}{n}(t_g - t_h) = t_g - \frac{1}{n}(t_g - t_h)$$

$$t_{2h}^{(n)} = t_g - \frac{2 + \frac{7}{3}}{n}(t_g - t_h) = t_g - \frac{13}{3n}(t_g - t_h)$$

Then formula 1 and formula 2 are true

If a=k, then testify when a=k+1, formula 1 and 2 are true

$$t_{(k+1)g}^{(n)} = 0.7t_{kg}^{(n)} + 0.3t_{kh}^{(n)}$$

$$= 0.7t_{kg}^{(n)} - \frac{0.7(k-1)}{n}(t_g - t_h) + 0.3t_g - \frac{0.3(k + \frac{7}{3})}{n}(t_g - t_h)$$

$$= t_g - \frac{k - 0.7 + 0.7}{n}(t_g - t_h) = t_g - \frac{k}{n}(t_g - t_h)$$

$$= t_g - \frac{[(k+1)-1]}{n}(t_g - t_h)$$

$$t_{(k+1)h}^{(n)} = t_{(k+1)g}^{(n)} - \Delta t^{(n)} = t_g - \frac{k}{n}(t_g - t_h) - \frac{10}{3n}(t_g - t_h)$$

$$= t_g - \frac{(k + \frac{10}{3})}{n}(t_g - t_h) = t_g - \frac{[(k+1) + \frac{7}{3}]}{n}(t_g - t_h)$$

Therefore, formula 1 and 2 are true.

If the heat intermedium inflow is linear with the outflow:

$$t_{pj} = \frac{t_g - \frac{(a-1)}{n}(t_g - t_h) + t_g - \frac{(a + \frac{7}{3})}{n}(t_g - t_h)}{2}$$

$$= t_g - \frac{(a + \frac{2}{3})}{n}(t_g - t_h) \quad (F3)$$

4.3 Analyze the situation with random inflow rate

If set inflow rate as 1/P, we can testify:

$$t_{ag}^{(n)} = t_g - \frac{(a-1)}{n}(t_g - t_h) \quad (F4)$$

$$t_{ah}^{(n)} = t_g - \frac{(a + P - 1)(t_g - t_h)}{n} \quad (F5)$$

From the above formulas, the inflow temperature of the radiator $t_{ag}^{(n)}$ has no relation with P, i.e. has no relation with inflow rate, but the outflow temperature $t_{ah}^{(n)}$ has relation with P.

Smaller P (bigger inflow rate), larger $t_{ah}^{(n)}$. The more heat intermedium flow into the radiators, the higher temperature of outflow will be got. The higher radiating capacity, the better radiating effect.

If the heat intermedium inflow is linear with the outflow, then the average temperature of the heat intermedium is:

$$t_{pj} = \frac{t_{a-1} + t_{ah}}{2} = \frac{t_g - \frac{(a-1)(t_g - t_a)}{n} + t_g - \frac{(a+P-1)(t_g - t_a)}{n}}{2}$$

$$= t_g - \frac{(a-1 + \frac{P}{2})(t_g - t_a)}{n} \quad (F6)$$

5. RADIATING CAPACITY STUDY OF HSS SYSTEM

When the average temperature of the heat intermedium is confirmed, the radiating capacity of the radiator unit can be worked out. For example, if the temperature is 95 °C ~ 70 °C , the room temperature is 20°C, and the radiator is 60 with long wings, according to the testing formula

$$Q = 5.30\Delta t^{1.345} \quad (3 \text{ units}) \text{ given in Ref}^{[4]}, \text{ the}$$

radiating capacity is as Table 2:

Tab.2 Heating Capacity Table of HSS System under temperature of 95~70°C

No. of Units	[Radiator Unit Diagram]									
	1	2	3	4	5	6	7	8	9	10
3	365	299	238							
4	393	343	294	248						
5	410	369	329	291	254					
6	421	387	354	321	289	258				
7	430	400	371	343	315	287	261			
8	436	410	384	359	334	310	286	263		
9	441	418	395	372	350	328	307	285	265	
10	445	424	403	383	362	343	323	304	285	266

Compare the data with 8 units in Table 2 and data of SLS system under the same condition given by Reg^[4], we get the Figure 6:

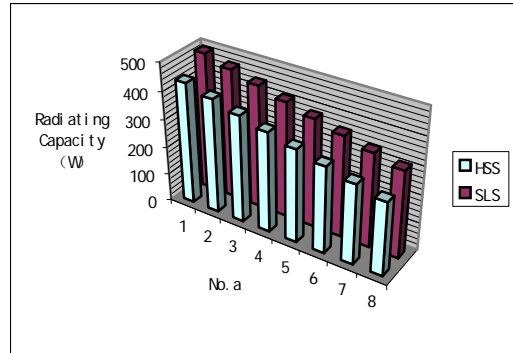


Fig. 6 Diagram of comparing heat of 8 sets of radiators

We can see that the radiating capacity of HSS System is reduced comparing with SLS system. Because many heat intermedium doesn't flow through the radiator due to the spanning line setting, and the temperature of the outflow through the radiators is lower. This results in the lower average temperature of the heat intermedium in radiators. By studying the compare table, we can also see that the slope of the HSS system is less than the SLS system. Though the radiating capacity of HSS system is reduced in some degree, but with the lower temperature of the inflow, the affect is less.

6. WHAT SHOULD BE NOTICED IN DESIGN

6.1 The radiator with too small load should be calculated with other units

When calculating the HSS system, the radiators with larger heat load can be split into two or more units. However, as for units with smaller load, we normally merge it with other units.

Comparing the data in Table 2, In line 3, the data in column 1 of line 3 is even lower than the column 2 of line 6. Because when one unit is split into two units, the outflow temperature of the first unit and the inflow temperature of the second unit are all increased, and the radiating capacity is increased accordingly. If calculating by splitting the radiator with larger load, the result will much lower than the actual data. Therefore, the radiator with too small load should be calculated with other units,

and the number of its former unit should be reduced 5%~10%. In addition, we can conclude that HSS system is not suitable for the design with larger radiating load.

6.2 The Correction of Radiating by the Pipeline

Normally in design computation, the heat radiated from pipeline is not considered. The heat load of the room is taken for the heat load of the radiators and the fraction of divisor is counted as integer. Consequently, the heat emitted by the beginning parts of radiators and the pipeline is higher than the designed room heat load, however the temperature of the terminal is lower than the designed one. When more radiators are added, the temperature falls even more and the radiating capacity is below the design data. This results in a hot beginning and a cold end. To solve this problem, when calculating the number of radiator units, we should give up the fraction in the beginning part and add the fraction as integer in the end part. Meanwhile, more radiating area should be considered. For example, the last 2 units add 15% more, the next two add 10%, and the next two add 5%.

6.3 No Spanning Line in the Radiator End

Because the total radiating capacity of the HSS system is lower, when the heat load of the end is higher and layout is difficult, we waive the spanning line in the end and adopt SLS system instead to get a better effect.

6.4 Diameter of Spanning Line

In practice, lower resistance temperature control valve and flow regulating valve are adopted in HSS system. As my study is carried out in a condition of inflow rate as 30%, the rate should be higher than 30% when the valve is open completely. In Ref^[5], the inflow rate in the pipeline with different diameter is given. It is clear that if the diameter of the spanning line is smaller one standard unit than the diameter of the inflow and outflow line, the inflow rate is always beyond 30% with the valve completely open. Therefore, we should follow this principle to design the diameter

of the spanning line.

7. APPLICATION IN PRACTICE

The method introduced in this article has been applied in one of the ongoing building project in Dalian and the feedback is good. Herein we take a house with the layout as Fig7 below as an example:

Based on the design method given in this article, we calculate the heat load of dinning room and kitchen together and deduct 5%; calculate bathroom and main bedroom together and deduct 5%. As the heating system ends in the living room, we don't use spanning line and connect the radiators as SLS system. According to the data in Table 2, the number of each radiating units could be got. The layout of the radiators as shown in Fig8:

After completion of this construction, the heating system is running smoothly. By frequent after service visits, no defect of design was found. To sum up, the design and computation method introduced in this paper is effective.

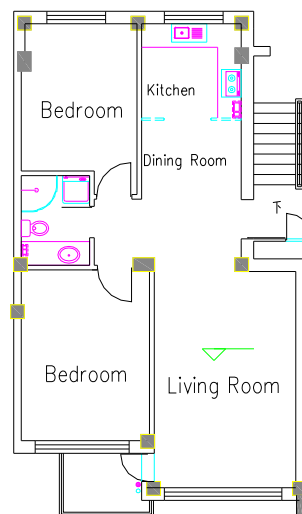


Fig 7 Structural plan of one pilot project in Dalian

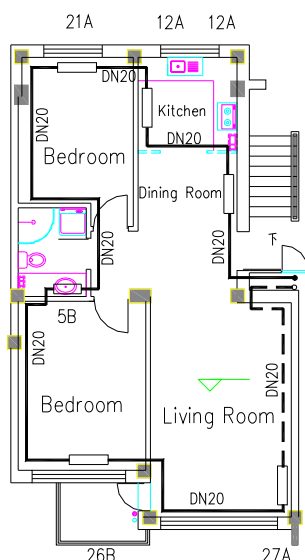


Fig 8 Heating plan of one pilot project in Dalian

8. CONCLUSION

With the rapid development of the market economy and the thorough reforming of housing system, the single household metering of heating system is the developing trend. It is also the only way to solve the difficulty of charging and realize the energy saving in the architecture aspect. The single house horizontal system including HSS system will become the main form of single house heating. Single house horizontal system is more complex than the traditional system. Its design requests updated design idea and computation methods. Therefore, it's important to study the design and computation of single house horizontal heating system. In sum, we can get the following conclusion,

- 1). Comparing the different forms of single house heating system, horizontal heating system is suitable to the current residence house in China.
- 2). In HSS system, it's not economic if diffidence rate is too large, because more radiator units are needed. However, if the rate is too small, though the control ability becomes worse, the number of radiators cannot be reduced. , considering the factors of control ability and

economy, it is reasonable to select 70 % as diffidence rate and 30% as inflow rate.

3). By studying the distribution rule of the heat intermedium in HSS system, the computation formula of the average temperature of heat intermedium and the radiating capacity is raised and verified. Meanwhile, a calculation table of the radiating capacity with different radiator units is given.

4). In HSS system, the inflow temperature has no relation with inflow rate, but the outflow temperature is related with inflow rate. i.e. the larger inflow rate, the higher radiating capacity, and the better radiating effect.

5). The radiator with too small load should be calculated with other units. The radiating by the pipeline should be corrected in the design. The radiator ends are designed without spanning line. And the diameter of the pipe line should be smaller than the lines with flow in and out

6). In the real project, the operation of the HSS system has been verified. It shows that the design and computation methods raised in this paper are convenient, reasonable, and accurate.

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