Sprinkler Coverage Design

Fluid Mechanics for HVAC

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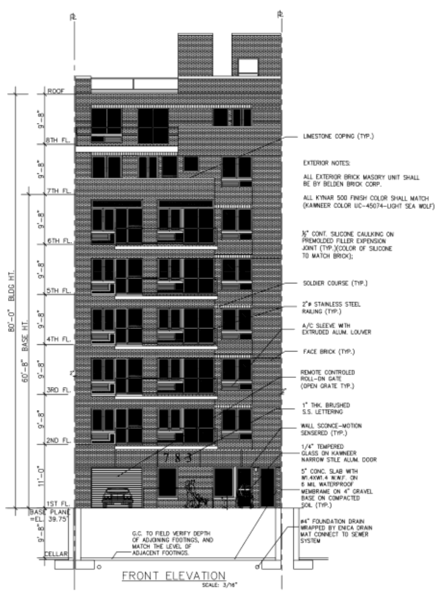
Introduction

This document serves as the basis of design for the installation of a sprinkler system for a residential building on East 9th street. This document will contain a brief explanation of our method of design, the reasoning behind why sprinklers were placed where they were, blueprints for where each sprinkler will be installed, and calculations for the pressure and flow rate of each sprinkler in the hydraulic zone.



The building is 8 stories tall and residential in nature. The first floor is used mainly as a garage; floors 2 through 7 each house two apartments each; the eighth floor houses a single large apartment; the roof has one small enclosed area which contains a staircase; the cellar is mostly an open area used for recreation for the building's tenants.

Our goal is to provide continuous sprinkler coverage so residents may safely exit the building from the main staircase if there's ever a fire emergency. We also wish to design our system efficiently enough that we reach the desired pressure at the most remote sprinkler head without needing to use a pump.

We will check the pressure and other factors at each sprinkler head in our remote hydraulic zone using the software 'Hass.' We will also check the values that Hass gives us manually to ensure the software worked correctly and that our sprinkler design is safe and reliable.

Methodology

The code we are following is NFPA13, but because of the nature of our building we will say that our hydraulic zone covers 900 square feet. Because the building contains a small number of apartments, we will consider the building to be a Light hazard.

We have chosen to use 12x12 sprinkler heads exclusively for our sprinkler system. The K value for these sprinkler heads is 4.9, and the manufacturer of these heads is Reliable. Our elbow and tee pipes will be assigned a K value of 0 for the purpose of our calculations, but we will consider an elbow pipe to add an extra 3 feet of pipe length, and a tee pipe to add an extra 5 feet of pipe length.

Because we are providing continuous coverage, our sprinkler heads cannot be more than 12 feet apart. We also require that sprinkler heads are positioned at least 4 inches away from the wall. In addition, each sprinkler head must be at least one foot away from an elbow pipe or a tee pipe.

Every room should be covered except for these exceptions: bathrooms under 55 feet squared don't require a sprinkler head, closets under 12 feet squared don't require a sprinkler head, electrical rooms don't require a sprinkler head, mechanical rooms don't require a sprinkler head.

For our calculations, our hydrant test flow rate is 500 gpm, our residual pressure is 83 psi, and our static pressure is 85 psi. Our RPZ is a fixed loss device that is valued at -12.

Calculations

The point of doing the calculations is to provide a check to see if we used the Hass software correctly, as well as ensure our design is safe and accurate. To check our manual calculations, we make use of two important equations.

The first is equation is the relationship between the pressure and the flow rate:

$$P = K * \sqrt{Q} \tag{1}$$

The second equation is the Hazen Williams equation which calculations the friction loss, h.

$$h = 0.002083 * L * \left(\frac{100}{C}\right)^{1.85} * \frac{Q^{1.85}}{d^{4.8655}} \tag{2}$$

L is the pipe length, C is the roughness, Q is the flow rate, and d is the pipe diameter.

We can modify the second equation to convert the units to psi and incorporate our roughness constant as such:

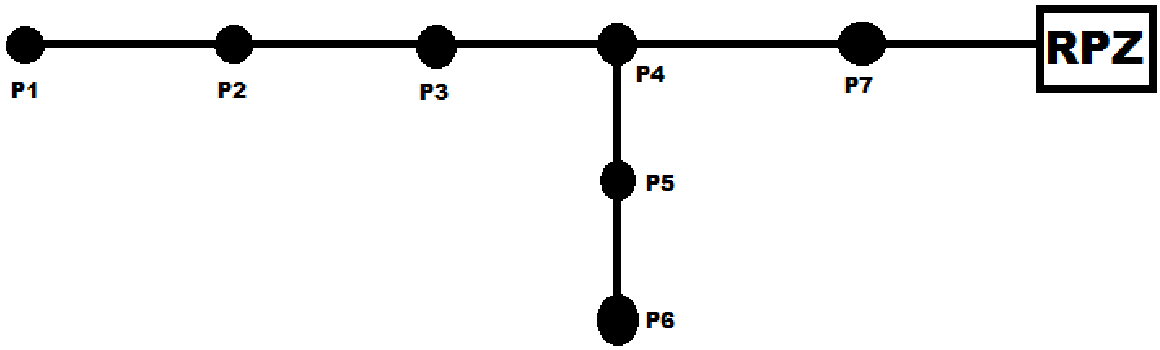
$$h = 0.00064 * L * \frac{Q^{1.85}}{d^{4.8655}} \tag{3}$$

Additionally, we will make use of the fact that the pressure at a node is equal to the pressure of next node away from it (further away from the RPZ) plus the pressure loss in that pipe. The equation looks like:

$$P_{close} = P_{far} + h \tag{4}$$

Manual Calculations

Let's go through an example of a sprinkler system to see how we'll do the manual calculations.



We will take the pressure of the most remote sprinkler head (in this example, P_1) from the Hass software. So we're given P_1.

We can easily calculate P_2 since we have P_1. We first calculate the flow of P_1 by rewriting Equation (1) to:

$$Q_1 = K_1 * \sqrt{P_1}$$

We have $K_1$and P_1 so Q_1 is calculated. From here, we use Equation (3) to find the friction loss between the pipes:

$$h_{2\rightarrow 1} = 0.00064 * L_{1-2} * \frac{{Q_1}^{1.85}}{{d_{1-2}}^{4.8655}}$$

We have $L_{1\text{-}2}$, we have $d_{1\text{-}2, \text{ and}}$ we just calculated Q_1. We can now find P_2 using Equation (4):

$$P_2 = P_1 + h_{2\rightarrow 1}$$

Using the same method, we can calculate P_3, P_4 and P_7.

To calculate P_5 and P_6 is a little trickier since they come off of a branch. However, the same formulas apply.

$$Q_5 = K_5 * \sqrt{P_5} \tag{5}$$

$$h_{4\rightarrow 5} = 0.00064 * L_{4-5} * \frac{Q_5^{1.85}}{d_{4-5}^{4.8655}} \tag{6}$$

$$P_5 = P_4 - h_{4\rightarrow 5} \tag{7}$$

(Notice that in Equation (7), the friction loss is subtracted from the previous node since we are moving further away from the source.)

P_5 is unknown and Q_5 is unknown. However, we have enough equations relating P_5 and Q_5 to solve for them. Replace the Q_5 in Equation (6) with the Q_5 in Equation (5) to get:

$$h_{4\rightarrow 5} = 0.00064 * L_{4-5} * \frac{(K_5 * \sqrt{P_5})^{1.85}}{d_{4-5}^{4.8655}}$$

If you plug that $h_{4->5}$ into Equation 7 and simplify things, then:

$$P_5 + P_5^{\frac{1.85}{2}} * \left[0.00064 * L_{4-5} * \frac{(K_5)^{1.85}}{d_{4-5}^{4.8655}}\right] - P4 = 0$$

This is a polynomial equation where P_5 is the only unknown. We can solve this and find P_5.

P_6 is solved the same way that P_5 was solved.

Using the calculations shown in this section, all of the calculations for our hydraulic zone can be calculated.

Program

Although we are doing these calculations ‘manually,’ we use the same equations over and over. To save time and avoid mistakes, we’ve created a simple program to do the calculations provided you input the parameters (the ‘knowns’) of our equations. This program will not only simplify things for us, but it will provide consistency and make sure we use the same parameters and equations for each calculation.

The program is written in C++ and can be compiled using Visual Studio C++ in Windows or a g++ compiler in Linux.

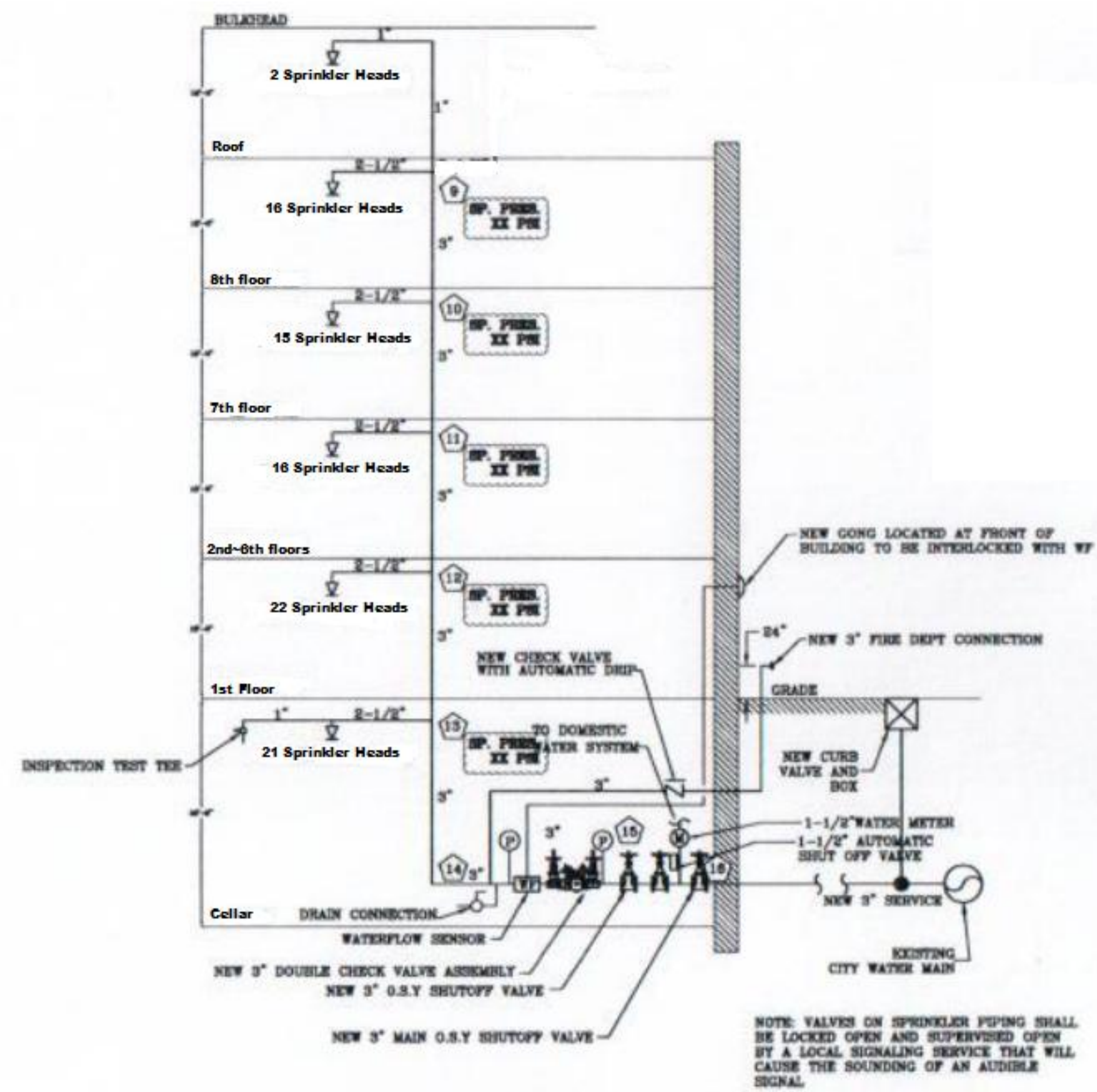
The source code is provided on the next page.

```
// Program to calculate the new pressure at a sprinkler head.
#include <iostream>
#include <cmath>
using namespace std;

void OutputAnswer(double pressure, double newq)
	{
	cout << "\nThe pressure (P) at this node is " << pressure << endl;
	cout << "The flow (Q) at this node is " << newq << endl;

	cout << "\nTo run the program again type any character and press enter. ";
	char zzz;
	cin >> zzz;
	cout << endl << endl;
	}

//Function for branches.
void CalculateBranch(double pressureprevious, double kprevious, double k, double
pipeLength, double diameter)
	{
	// P5 + [P5^1.85/2]*[0.00064*L*(K5^1.85)/(d^4.8655)] - P4 = 0
	double pressure = 7;
	for (double count = pressure; count <= pressureprevious ; count + 0.0001)
		{
		pressure = pressure + 0.0001;
		double LHS = pressure + pow(pressure, 1.85/2)*0.00064*pipeLength*pow(k,
1.85)/pow(diameter, 4.8655) - pressureprevious;
		if (LHS >= -0.001 && LHS <= 0.001)
			{
			double newq = k*sqrt(pressure);
			OutputAnswer(pressure, newq);
			break;
			}
		}
	}

void CalculateNode(double pressureprevious, double q, double kprevious, double k, double
pipeLength, double diameter)
	{
	// Find flow of previous pipe.
	double qprevious = kprevious*sqrt(pressureprevious);

	if (qprevious == 0)
		{
		qprevious = q;
		}

	//double friction = 0.002083 * pipeLength * pow(100/C, 1.85) * (pow(qprevious,
1.85) / pow(diameter, 4.8655));
	double h = 0.00064*pipeLength*pow(qprevious,1.85)/pow(diameter, 4.8655);

	double pressure = h + pressureprevious;

	double newq = k*sqrt(pressure);

	OutputAnswer(pressure, newq);
	}
```

```
void GetInfo()
	{
	int x;
	cout << "If the node we're calculating is on a branch, type 1. \nIf the node isn't
on a branch, type 2. ";
	cin >> x;

	if (x == 1 || x == 2)
		{
		}
	else
		{
		cout << "\nError. Please enter the number 1 or the number 2." << endl;
		GetInfo();
		}

	// Ask for the input values.
	double pressure;
	cout << "\nEnter the pressure of the previous node. ";
	cin >> pressure;

	double q;
	cout << "Enter the Q of the previous node. ";
	cin >> q;

	double pk;
	cout << "Enter the K value for your previous node. ";
	cin >> pk;

	double k;
	cout << "Enter the K value for your current node. ";
	cin >> k;

	double pipeLength;
	cout << "Enter the pipe length in feet (convert any inches to a decimal). ";
	cin >> pipeLength;

	double diameter;
	cout << "Enter the diameter of your pipe (inches). ";
	cin >> diameter;

	// Pass the values into the calculate function.
	if (x == 1)
		{
		CalculateBranch(pressure, pk, k, pipeLength, diameter);
		}
	else
		{
		CalculateNode(pressure, q,  pk, k, pipeLength, diameter);
		}
	}

int main()
	{
	GetInfo();
	return main();
	}
```

Sprinkler System

The building we're providing coverage to is 8 stories tall. A total of 140 sprinklers are required, distributed as seen in the following riser diagram. For specific sprinkler layouts for each floor, please consult the diagrams at the end of this report. Our focus will be of the 8th floor.



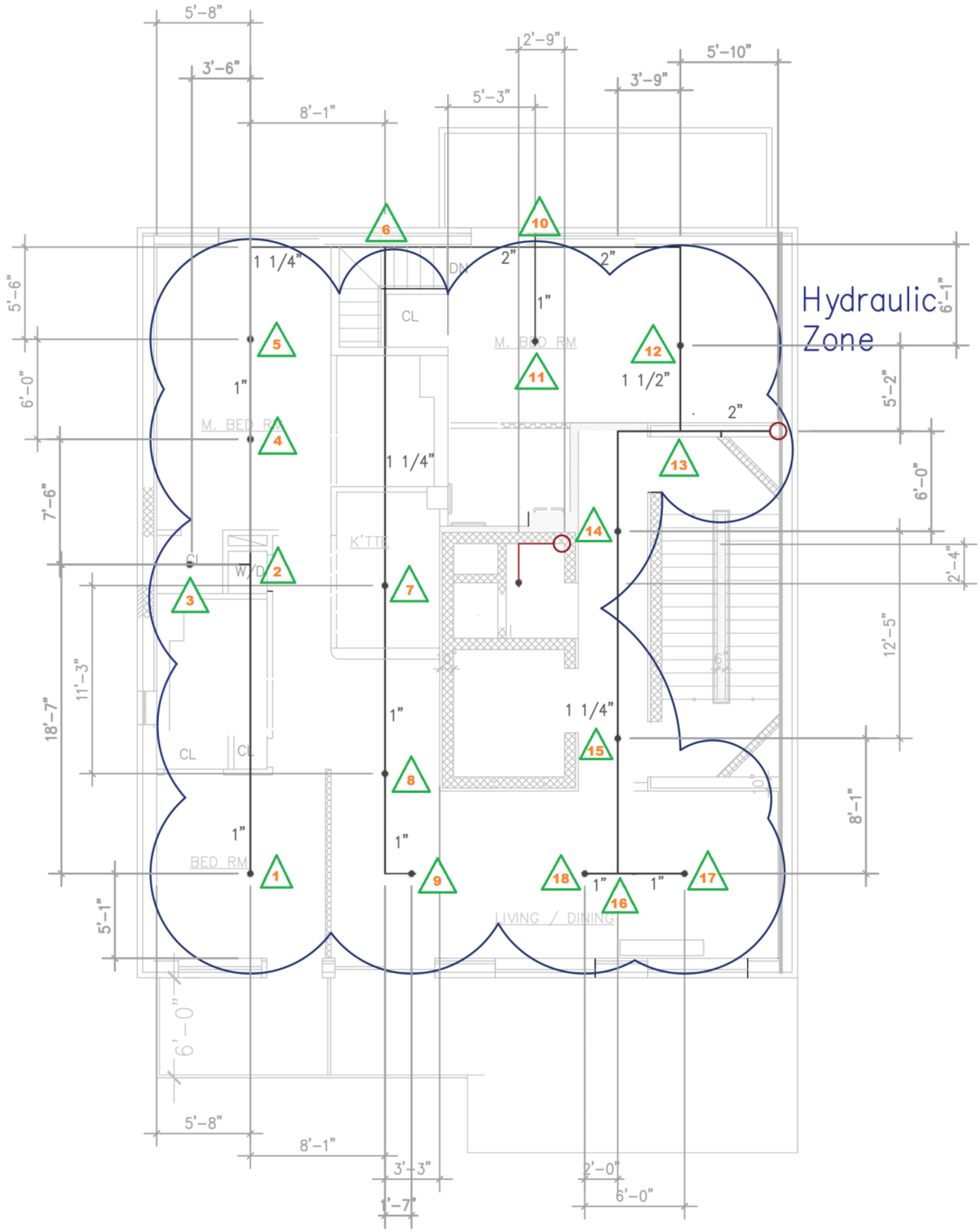
SPRINKLER RISER DIAGRAM
NTS

Remote Zone

The remote zone is the zone furthest away from the source of our water. In this case, our remote zone is the 8th floor of this building. We choose to do the calculations furthest away from the water source because if we can achieve the desired pressure far away from the source, then we know we'll have ample pressure for the rest of our system since the pressure increases the closer you get to the source.

We have labeled our remote zone by clouding in the coverage area. The nodes in the remote zone are numbered in the triangles in the picture. We choose the most remote sprinkler head to be node 1. The pressure at this sprinkler head must be above 7 psi to provide adequate coverage.

The rest of the sprinkler heads must be above 7 psi, but since node 1 is the most remote node it should have the lowest pressure. We will use the Hass software on this remote zone to determine the pressure we achieve at node 1 for the given parameters for our building. If it is above 7 psia and if our manual calculations match those of Hass's to some degree, we will have succeeded and our design will be considered sufficient.



8TH FL. PLAN

SCALE: 3/16"

Hass

A detailed account of Hass is provided near the end of this report. For our discussion we will only need to look at the output received when inputting the information for the remote zone.

NFPA WATER SUPPLY DATA

SOURCE NODE TAG	STATIC PRESS. (PSI)	RESID. PRESS. (PSI)	@	FLOW (GPM)	AVAIL. PRESS. (PSI)	@	TOTAL DEMAND (GPM)	REQ'D PRESS. (PSI)
SOURCE	85.0	83.0		500.0	84.4		252.8	

AGGREGATE FLOW ANALYSIS:

TOTAL FLOW AT SOURCE	252.8 GPM
TOTAL HOSE STREAM ALLOWANCE AT SOURCE	0.0 GPM
OTHER HOSE STREAM ALLOWANCES	0.0 GPM
TOTAL DISCHARGE FROM ACTIVE SPRINKLERS	252.8 GPM

NODE ANALYSIS DATA

NODE TAG	ELEVATION (FT)	NODE TYPE	PRESSURE (PSI)	DISCHARGE (GPM)	NOTES
1	80.0	K= 4.90	11.9	16.9	
2	80.0	- - - -	13.6	- - -	
3	80.0	K= 4.90	13.2	17.8	
4	80.0	K= 4.90	16.2	19.7	
5	80.0	K= 4.90	17.5	20.5	
6	80.0	- - - -	15.3	- - -	
7	80.0	K= 4.90	12.1	17.0	
8	80.0	K= 4.90	9.2	14.8	
9	80.0	K= 4.90	8.4	14.2	
10	80.0	- - - -	21.1	- - -	
11	80.0	K= 4.90	20.3	22.1	
12	80.0	K= 4.90	25.3	24.6	
13	80.0	- - - -	26.5	- - -	
14	80.0	K= 4.90	23.5	23.8	
15	80.0	K= 4.90	20.1	22.0	
16	80.0	- - - -	16.4	- - -	
17	80.0	K= 4.90	15.9	19.6	
18	80.0	K= 4.90	16.4	19.9	
19	0.0	- - - -	72.4	- - -	
20	0.0	- - - -	84.4	- - -	
SOURCE	0.0	SOURCE	84.4	252.8	

We can see that at node 1 the pressure is 11.9 psi. This is above the minimum 7 psi we require, so our sprinkler design should work if Hass is correct in this analysis.

We must verify Hass's values by doing the manual calculations ourselves.

Manual Calculations and Comparison

We entered the necessary values for the program explained in an earlier section of the report onto a spreadsheet. The manual calculations only used the value for Node 1 from Hass, and the rest were manually taken. The spreadsheet is provided here:

Sprinker Calculations

Node	Attached to Node	Branched? (1 if yes)	Previous Pressure	Previous Flow Q	Previous K	K	Pipe Length	Pipe Diameter	Hass Pressure	Manual Pressure	Manual Flow (GPM)
1	-	-	-		-	4.9	-	-	11.9	-	
2	1	2	11.9	16.9	4.9	0	17.167	1	13.6	13.9541	16.9
3	2	1	13.9541	16.9	0	4.9	3.667	1	13.2	13.4614	17.978
4	2	2	13.9541	16.9	0	4.9	7.25	1	16.2	14.8213	18.8642
5	4	2	14.8213	18.8642	4.9	4.9	6	1.25	17.5	15.1183	19.0523
6	5	2	15.1183	19.0523	4.9	0	13.333	1.25	15.3	15.7905	19.0523
7	6	1	15.7905	19.0523	0	4.9	20.333	1.25	12.1	14.7853	18.8413
8	7	1	14.7853	18.8413	4.9	4.9	11.25	1	9.2	13.2931	17.8653
9	8	1	13.2931	17.8653	4.9	4.9	10.5	1	8.4	12.0237	16.9909
10	5	2	15.1183	19.0523	4.9	0	27.333	2	21.1	15.2583	19.0523
11	10	1	15.2583	19.0523	0	4.9	5.5	1	20.3	14.4688	18.6386
12	10	2	15.2583	19.0523	0	4.9	22.67	2	25.3	15.3744	19.213
13	12	2	15.3744	19.213	4.9	0	5.167	2	26.5	15.4013	19.213
14	13	1	15.4013	19.213	0	4.9	12.75	1.5	23.5	15.1353	19.063
15	14	1	15.1353	19.063	4.9	4.9	12.417	1.25	20.1	14.5309	18.6785
16	15	1	14.5309	18.6785	4.9	0	8.083	1	16.4	14.53	18.6785
17	16	1	14.53	18.6785	0	4.9	4	1	15.9	13.9738	18.317
18	16	1	14.53	18.6785	0	4.9	2	2	16.4	14.5192	18.671
Fixed Loss	13	2			0	4.9	146.83	3	72.4	-	-
Source	Fixed Loss	2						4	84.4	-	-

A bigger version of this spreadsheet will provided at the end of this report. We will provide analysis of the numbers in the next section.

Analysis

A close up of the Hass values for the pressure compared to the manually calculated pressure is shown in the following picture.

Hass Pressure	Manual Pressure
11.9	-
13.6	13.9541
13.2	13.4614
16.2	14.8213
17.5	15.1183
15.3	15.7905
12.1	14.7853
9.2	13.2931
8.4	12.0237
21.1	15.2583
20.3	14.4688
25.3	15.3744
26.5	15.4013
23.5	15.1353
20.1	14.5309
16.4	14.53
15.9	13.9738
16.4	14.5192

We can see that initially the numbers are close, but trending toward the middle there is a noticeable difference between the Hass pressure and the manually calculated pressure.

These differences are perfectly okay and does not deter us. The most important thing is that we see the trends of the numbers increase or decrease by comparative amounts that are still within the bounds of our acceptance. (Namely, everything is still above 7 psi and there are no huge jumps in numbers.)

The reason for the difference is for three reasons. The first reason is that Hass calculates the pressure at each node by taking into consideration extra parameters, such as the fixed loss device, the flow rate at the source, the residual and static pressures, the elevation etc. It is understandable that our manual calculation is simplified compared to the depth that Hass goes into.

The second reason for the difference in numbers is that for our manual calculations, there is difficulty in saying that a node has a K value of 0. If a node has a K value of 0 then that effectively says that the flow of that node is 0 gpm, which in turn affects our Hazen-Williams equation by telling it there is no pressure loss (h) at that pipe. For our calculations in situations where there is a tee pipe, we take the flow of the previous node as the flow of that particular node we are working with and that gives us roughly what we need, but even then the numbers become off.

The third reason for the difference in numbers is the rounding error incurred by using the last manually calculated pressure for further calculations. That is to say, if we calculate the pressure at node 2 and it is a little off from what Hass says the pressure at node 2 is, then by using the manually calculated node 2 that is a little off, we will further increase error as we continue calculating nodes. The further away we move from node 1 the more off our calculations will get because errors keep adding up.

However, the reasons for these errors did not affect us. Our calculations, although off from Hass's values, are comparative enough in trends to show us that both Hass and our calculations deem our remote zone a success.

Conclusion

We have successfully designed a sprinkler system for the 8 floor residential building in question. Our diagram has shown that there is continuous coverage for each room and for every floor of the building. The design is sufficient enough that given a fire emergency, the residents, no matter where they may be in the building, can successfully be protected from the fire and may successfully reach the staircase to escape from the building unharmed.

Given our chosen parameters, our Hass and manual calculations for the most remote zone show that we've achieved a desired pressure which is enough to supply adequate flow to the whole building and which will support the entirely covered system.