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THE INFLUENCE OF LOCATION OF HOT WATER PIPE ON BUILDING THERMAL BEHAVIOR

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ABSTRACT

This paper presents the numerical simulation of several buildings located in Seoul city with different domestic hot water distribution. The simulation is completed on the TRNSYS based platform by simulating the influence of pipe location on the building room temperature and heat load. A position factor is proposed as a criterion to evaluate pipe position influence. Simulations are also carried out under different hot water temperature and different weather conditions, seasonal heat loss quantities are also considered. In order to know the whereabouts of heat loss, influence of heat loss on room air, walls and adjacent rooms are also taken into account. The simulating results show that in cold area like Seoul, pipes locate next to east external wall can bring biggest benefit to building room temperature and heat load. Position factor grows proportionally with water temperature and during fall season buildings get most effective heat loss from pipe. Furthermore, the room temperature difference caused by pipe location can be as big as 1℃.

INTRODUCTION

With the increase in the cost of energy and high energy consumption in industry, building, transportation and agriculture sectors, especially buildings have recently received considerable attention on energy consumption because of heat loss (Ali Keçebas, 2011). In residential buildings, energy consumption of domestic hot water systems is proved to be the third level after heating system and lighting systems. District Heating (DH) system can reduce heating and hot water system energy waste, increase energy efficiency and control the emission of CO^2 and NO_X, so more and more counties are engaged in developing District Heating system.

In District Heating system, heat is delivered through pipelines those are composed of two separate pipeline zones. The primary pipeline zone covers the lines from CHP plant to the apartment's heating facilities while the secondary zone covers from heating facilities to individual apartments. The primary pipeline is well installed to minimize heat loss by the utility company providing district heating in Korea. However, the secondary pipelines constructed by independent construction companies, which can be subject to a lot of heat loss due to poor engineering practice and poor management (Byung-sik Park, Yong-Eun Kim, 2010, 2012) .

Usually in the secondary pipeline zone, there are five pipes for supplying hot water, heating water, city water and the return pipe for heating and domestic water. All of these five pipes are in the same duct located usually next to stairs or in the washroom to save space. The water temperature in heating pipe is usually from 70℃ to 90℃, and the water temperature in hot water pipe is almost 45℃ to 80 ℃, while room temperature proved to be around 20 ℃ to 30 ℃, heat will transport whenever there are temperature differences, this transported heat can be called heat loss from pipe to room environment. Pipe layout, pipe size, materials and insulations, also water temperature and room temperature can affect heat loss. Several studies have been performed to investigate heat loss affection factors about hot water piping system. The California Energy Commission embarked on quantifies the time, water, and energy waste characteristics with changing pipe length, volume sites, insulation and room moisture presence (Hot Water Distribution System Research – Phase I, 2005). However, few studies focus on pipe location affects.

According to the above introduction, it can be clearly seen that domestic pipelines need more standardized design. This paper mainly focus on the influence of pipe location in household and a position factor is proposed to evaluate suitable pipe location. Several building models and piping distribution system are made in order to: 1) study the influence on room temperature and building load of different pipe location; 2) study the influence by different water temperature, weather data and seasons; 3) find out the most affected area by pipe heat loss.

TRNSYS

TRNSYS

TRNSYS is a transient systems simulation program. It is designed to simulate the transient behaviour of thermal energy systems. Simulation systems are

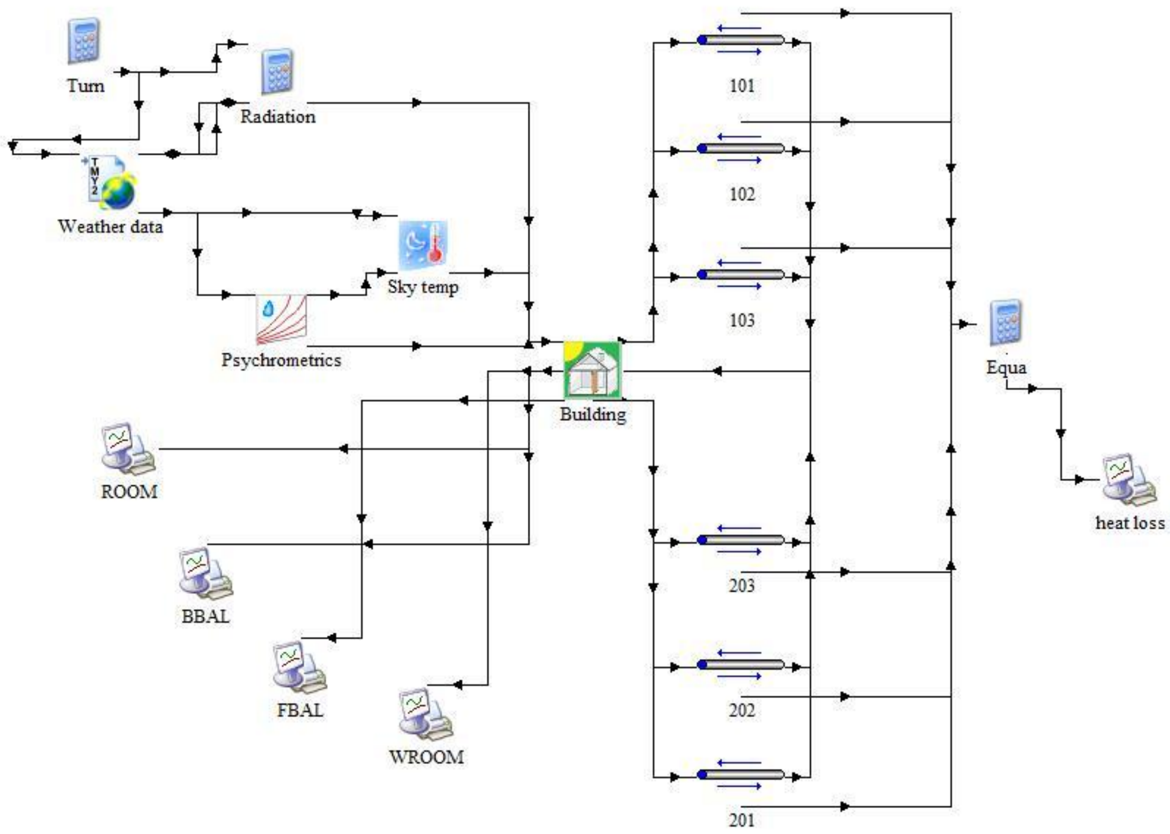

Figure 1TRNSYS studio representation of hot water domestic system

conformed by components which can be chosen from TRNSYS library, and users can link these components together through linking inputs and outputs.

We utilized many components from the standard TRNSYS component library in this paper. The major components are Type 56 (Building model), Type 604 (Pipe model) and weather data part. More detailed composition of types can be found in Figure 1. Other minor components used in this simulation functioned as equations and output plotters.

Type 109, Type 69 and Type 33 are weather data reader and radiation processor. These components can read weather data at regular time intervals from a data file, and converting it to a desired system of units and processing the solar radiation data to obtain titled surface radiation and angle of incidence for an arbitrary number of surfaces. Type 109 reads a weather data file in the standard TMY2 format. The TMY2s are data sets of hourly values of solar radiation and meteorological elements for a 1-year period, these sets are derived from the 1961-1990 National Solar Radiation Data Base (NSRDB) (TRNSYS, Weather data, 2010). The weather data file in this research is mainly in Seoul, South Korean, but for later comparison, weather data of Singapore and Paris are also used.

Type 56 (Building type mathematic)

This component describes a simplified method of providing heating and cooling equipment. Building model in Type56 is an energy balance model. According to energy balance, convective and conductive flux to the air node can be described as below:

$$\dot{Q}_i = \dot{Q}_{surf,i} + \dot{Q}_{inf,i} + \dot{Q}_{vent} + \dot{Q}_{g,c,i} + \dot{Q}_{cplg,i} \quad (1)$$

Where $\dot{Q}_i$ means convective and conductive heat flux is consisted by the surfaces heat gains $\dot{Q}_{surf,i}$ (convection from the outdoor temperature), the infiltration gains $\dot{Q}_{inf,i}$, ventilation gains $\dot{Q}_{vent}$, internal gains $\dot{Q}_{g,c,i}$ like radiators, people, computer used in the room, and also the gains due to connective air flow from adjacent zones $\dot{Q}_{cplg,i}$, All of these quantities are given in kJ/hr.

While radiative heat flows to the walls and windows can be described as,

$$\dot{Q}_{r,w_i} = \dot{Q}_{g,r,i,w_i} + \dot{Q}_{sol,wi} + \dot{Q}_{long,wi} + \dot{Q}_{wall-gain} (2)$$

Where $\dot{Q}_{r,w_i}$ is the radiative gains for the wall surface temperature node, $\dot{Q}_{g,r,i,w_i}$ is the radiative air node internal gains received by wall, $\dot{Q}_{sol,wi}$ is the solar gains through zone windows received by walls, $\dot{Q}_{long,wi}$ is the long wave radiation exchange between this wall and all other walls and windows, and $\dot{Q}_{wall-gain}$ is the user-specified heat flow to the wall or window surface. All of these quantities are given in kJ/hr.

Each heat flux showed in (1) and (2) can be an equation of the temperature differences, so we can know the room temperature from these two equations. In this paper, we ignore the infiltration and ventilation gains to buildings and there are not any active layers in walls, like heating system set in the floor or wall.

With different pipe location in a building, the influence by outdoor environment is different. These will make the washroom temperature different directly. Furthermore, affect other room temperature and building heat load. Also in Type 56, we consider the long wave radiation happened between inner surfaces of walls and windows, it can be describe as below:

$$G_{ir} = (\text{I-F}\rho_{ir})\text{-1 F}\varepsilon_{ir} \qquad (3)$$

Where ρ_{ir} and ε_{ir} are diagonal matrices describing reflectivity and emissivity, respectively. The variable I describes the identity matrix. The view factor F is defined as the fraction of diffusively radiated energy leaving from surface A that is incident on surfaces B. The factor F has a closed contact with pipe location and direction. Above mentioned reasons relate the building thermal behaviour with respect to pipe position.

Type604 (pipe type mathematic)

This component models the thermal behaviour of fluid flow in a pipe or duct using variable size segments of fluid. Entering fluid shifts the position of existing segments. The mass of the new segment is equal to the flow rate times the simulation time step. The new segment's temperature is that of the incoming fluid. The outlet of this pipe is a collection of the elements that are "pushed" out by the inlet flow. This "plug-flow" model does not consider mixing or conduction between adjacent elements.

For elements that enter or leave during a particular time step, only the duration of time within the pipe is considered. The total energy loss rate to the environment is the summation of the individual losses from each element given as:

$$\dot{Q}_{surface,pipe} = h_{outside} SA\, (T_j - T_{env}) \qquad (4)$$

In which $h_{outside}$ is the natural convective heat transfer coefficient, SA is the surface area of the insulation node, T_j is outside surface temperature of pipe insulation and T_{env} means the environment temperature of rooms.

SIMULATION SYSTEM DESCRIPTION

Case model

In the first system, we suppose the domestic pipe is in washroom, so three different cases with different location of washroom are made and in every case [Fig 2], there is a simple one house with an area of 138m^2, and include four zones: back balcony, front balcony, room and washroom.

For the temperature settings, we define room temperature between 20 ℃ to 26 ℃, for washroom, there is no heating or cooling equipment. Temperature in front and back balcony are out of control and change with outside weather data. Table 1 shows parameters about building walls.

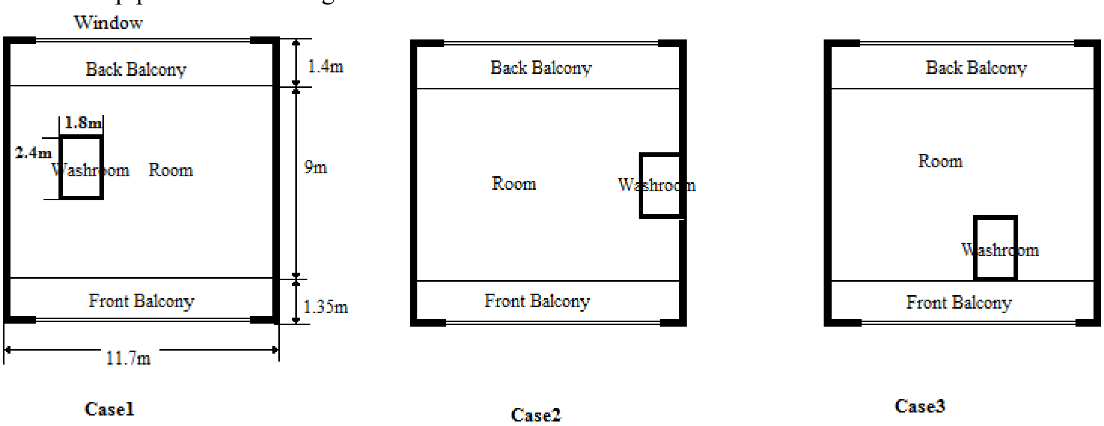

Figure 2 Different Washroom Location Cases

COLUMN 1	LAYER	LAYER THICKNESS (m)	WALL THICKNESS (m)	U-VALUE (W/m^{2}K)	SOLAR ABSORPTANCE OF WALL	LONGWAVE EMISSION COEFFFICIENT
Ext-wall	mortar	0.018	0.428	0.248	0.600	0.900
	Brick	0.090				
	Insulation	0.050				
	Concrete	0.200				
	Insulation	0.070				
Ext-roof	Plywood	0.002	0.220	2.202	0.600	0.900
	concrete	0.200				
Ground-floor	Concrete	0.200	0.230	1.941	0.600	0.900
	Timber	0.030				
Boundary-wall	fictitious	0.020	0.020	5.295	0.600	0.900
Adj-wall	Mortar	0.018	0.086	3.802	0.600	0.900
	Brick	0.050				
	Mortar	0.018				

Table 1 Building Wall

Pipe length	3 m	insulation density	70 kg/m^3
Pipe inner diameter	0.1 m	insulation thermal conductivity	0.026 W/m·K
pipe outer diameter	0.101 m	insulation specific heat	1.045 kJ/kg·K
pipe density	8933 kg/m^3	fluid density	1000 kg/m^3
pipe thermal conductivity	393 W/m·K	fluid thermal conductivity	0.613 W/m·K
pipe specific heat	3.97 kJ/kg·K	fluid specific heat	4.19 kJ/kg·K
insulation thickness	0.0254 m	fluid viscosity	3.078 kg/m·h

Table 2 Pipe parameters

Building model 1

In order to compare with actual situation, the whole apartment building complex are modelled. Three building models [Figure 3] are constructed corresponding to the three cases with different washroom locations. Each building model has 3 floors and two units (12 households), the materials of building and pipes are all the same as case models shown in Table 1 and Table 2.

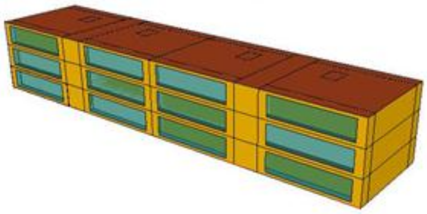

Figure 3 Building model 1

Pipe settings of model 1

In this research, we only consider the heat loss from hot water supply pipe. Mainly three kinds of hot water pipe can be used in buildings: main pipes set in the basement of building, vertical pipe transmit water from lower floor to higher floor, and branch pipes transfer water to each room. Here only vertical pipes are considered. The working fluid in pipe is water which supply temperature is 80 ℃, flow rate is 3600 kg/hr.

In this simulation system, pipe parameter show as table 2. Pipe radiation and convection heat flux connected to each zone as inputs and room temperature is used as the ambient temperature for pipes.

Building and pipe model 2

Above mentioned models presented the effects of washroom location, while another possible situation is in the same house, when pipe located in different room, different heat loss values are obtained also. For these reason, we make a single house model with five zones: Back balcony, Room 1, Room 2, Living room and Front balcony [Fig4]. There are no infiltration and ventilation gains, and we regard pipes as internal gains. Other parameters and material of house are all the same with model 1.

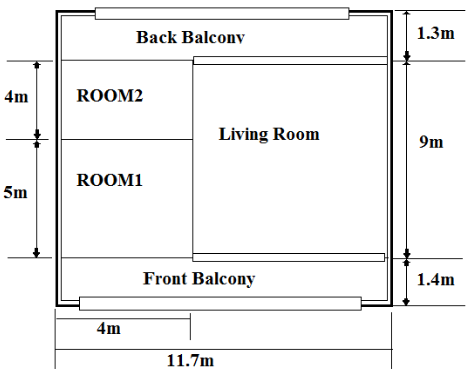

Figure 4 Building model 2

SIMULATION RESULTS AND DISCUSSION

Annual simulations are carried out under the TRNSYS environment with a 1-hour time step. Systems with different pipe locations in the climatic conditions in Seoul are investigated. The location influence can be compared though room temperature, pipe heat loss, building heat load, another standard called position factor is proposed in this paper. In order to explore the pipe heat loss affection to room wall and adjacent zone, a single house building with five rooms are made.

Temperature Change

Weather condition in Seoul can be divided into four distinctive seasons. The weather temperature changes along each season. -15 ℃~-20 ℃ can be reached during winter season from December to February, 25 ℃~30 ℃ can be reached during summer season from May to August, other seasons are with quite mild weather. In this simulation, washroom temperature can be affected only by weather condition, and different locations. Figure 5 shows washroom temperature change curve.

In Figure 5, temperature changes continuously through the year, because there is no heating device in washroom, so it changes according to weather only. The blue line means case 1, when pipe locates in the middle of room, it changes most gently because it affected by room temperature directly, while for case 2, the red line have lower temperature in winter than case 1 and higher temperature in summer, that because one of the washroom wall is a part of external wall, it can transfer heat from environment directly from outside. In case 3, the green line changes dramatically, because one of the washroom walls is next to front balcony and can be radiated by solar condition. From case 3, the lowest temperature maybe 5 ℃ lower than case 1 and 2, which can conclude as case 1 and 2 are more comfortable than case 3 when temperature is taken into major consideration.

$$\text{Position factor (\%)} = \frac{effective\ heat\ loss}{total\ heat\ load\ with\ pipe} = \frac{positive\ heat\ loss - negative\ heat\ loss}{total\ heat\ load\ with\ pipe} \quad (6)$$

Energy load difference

Except for temperature, heating load is another important parameter for building. In the building model, the lowest room temperature is set at 20 ℃ while the highest at 26 ℃, and the annual heating and cooling load can be calculated by TRNSYS.

Water temperature in pipe is always around 70~80 ℃, but room temperature keeps between 20~26 ℃, as a result, heat loss happens all around the year from pipe to room. During winter, this heat loss can be a positive heat to room, which can improve room temperature, however, during summer when it needs to move heat out, the heat loss from pipe can be a negative heat. In this case, here is a standard as position factor to evaluate pipe location influence on building heat load,

Where "total heat load with pipe" means the total heat load all over the year when pipe is in washroom, effective heat loss means the amount of useful heat pipe transferred to washroom, equals the positive heat from pipe subtracts negative heat loss.

Then, position factors in these three different buildings are as below [Table 3].

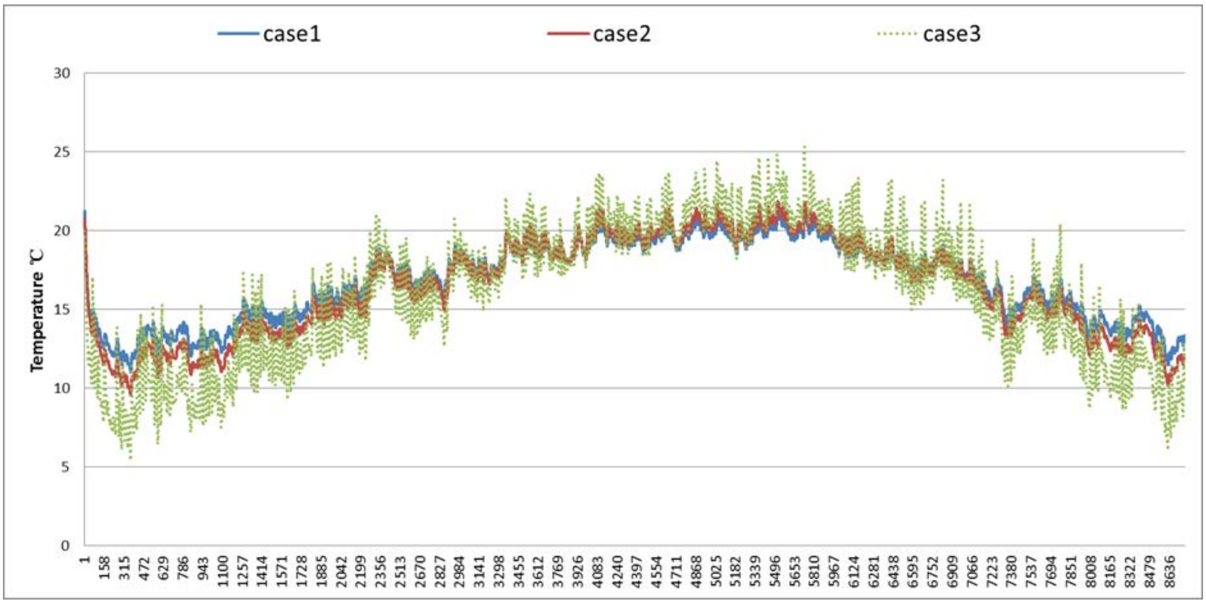

Figure 5 Annual washroom temperature

		PIPE	NO PIPE	DIFFERENCE	TOTAL	%
BUILDING1	HEATING LOAD	508921626	517276231	8354605(P)	7974481	1.554
	COOLING LOAD	4349501	3969377	380124(N)		
BUILDING2	HEATING LOAD	489320540	498673687	9353147(P)	8876212	1.797
	COOLING LOAD	4572105	4095170	476935(N)		
BUILDING3	HEATING LOAD	541101692	548752396	7650704(P)	7157386	1.306
	COOLING LOAD	6909178	6415860	493318(N)		

Table 3 Building heat load comparison (kJ)

In table 3, we divide heat load into heating and cooling load, "pipe" means there are pipes in washroom, while "no pipe" means there are no pipe in the building. "Difference" is how much heat decrease after setting up pipe, where P is positive, N is negative. "Total" is the total heat load increment. The percentage is position factor, where 1.554 means 1.554% influence to the whole building heat load. From table 3, we can know building 2 has the highest position factor, which means building can get more profit from pipe heat losses.

For pipe heat losses, outdoor weather data can also be an external factor, while water temperature in the pipe is an inherent influence factor. We also get the influence on position factors from these two aspects (Figure 6 and Table 4.)

Figure 6 shows position factor change with different water temperature. In all of the three buildings, position factor shows a linear relationship with water temperature. From upper to lower is red, blue and green, respectively. It also explained building 2 has the best position factor. If we consider the increasing rate of each line, the red line increasing rate can be twice than other two lines. Thus, we can conclude pipe water temperature effect pipe location factor of building 2 most. Although water temperature in pipe is usually decided by building energy consumption and consider more about outdoor pipeline settings, we still need to know how does water temperature effect position factor.

In order to study the different performance of position factor in different weather data, we choose three cities in Seoul, Singapore and Paris. Seoul is four distinct seasons city, the lowest temperature can be -15 ℃ while the highest can be almost 30 ℃, Paris also has four seasons but the temperature differences is much smaller than in Seoul, Singapore is a tropical rainforest climate, mean temperature around the year is about 23 ℃~34 ℃. From the data in table 4, we notice for colder cities like Seoul and Paris, building 2 is more suitable but in hot weather cities like Singapore, heat loss from pipe can affect very few positive effects and even negative effects to buildings. Another conclusion from table 4 is that in cities with four seasons, the more warm place are can be affect more by pipe heat losses.

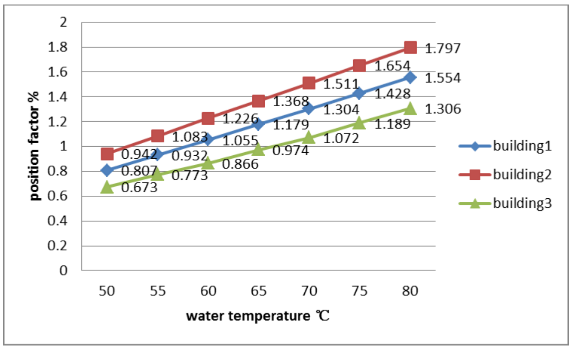

Figure 6 position factors under different water temperature(%).

CITIES	BUILDING 1	BUILDING 2	BUILDING 3
Seoul	1.554	1.797	1.306
Singapore	0.674	0.223	-1.091
Paris	1.739	2.035	1.506

Table 4 Position factors in different cities (%)

SEASON	LOAD	PIPE	NO PIPE	DIFFERENCE	TOTAL	%
Spring(3-5)	Heating	122758788	125112535	2353747p	2350840.3p	1.915
	Cooling	6345.966	3439.242	2906.724n		
Summer(6-8)	Heating	30306975	31563554	1256579p	2251303n	-7.323
	Cooling	435612	3943494	3507882n		
Fall(9-11)	Heating	100613496	102752779	2139283p	2125539.84p	2.112
	Cooling	28698.13	14954.97	13743.16n		
Winter(12-2)	Heating	255155130	257756944	2601814p	2601814p	1.019
	Cooling	0	0	0		

Table 5 Building heat load in four seasons (kJ)

Four seasons position factors

From above results, pipe heat loss can give positive heat to building all over the year. Usually, during winter, heat loss to buildings can reduced heating load, while during summer heat loss from pipes can increase cooling load. However, it is not clear that how much heat loss happens to building during spring and autumn. In this paper, we set the lowest room temperature as 20 ℃ and the highest temperature as 26 ℃, but there is no season control, it means no matter which season, the heating system will work as soon as the room temperature is lower than 20 ℃, this maybe not as actual situation, but we still can find seasonal changed position factors.

In table 5, position factors in spring is a little lower than that in fall, winter position factor improves to be the lowest one. For summer season, negative number means pipe heat loss do not benefit room temperature.

Pipe influence to different rooms

Heat losses from pipe cause by radiation from pipe surface and convection between room temperature and pipe temperature. In order to know whereabouts of heat loss, heat loss influence on room air, walls and adjacent rooms are also taken into account. As shown in Figure 7, the blue line presents heat loss from pipe, the red line presents heat amount absorbed by room air. It is easy to see the two curves change as the same trend, and the amount absorbed by room environment is about 85% of the total heat loss from pipe. Others about 15% heat loss is absorbed by walls and windows as long wave radiation.

For the purpose of investigating how much heat loss influenced on each room in the building, model 2 was simulated and got the temperature results as shown (Figure 8-12).

In building model 2, when pipe is in front balcony. We calculate the radiation and convection from pipe, the heat absorption by indoor room air, the heat absorbed by wall and the heat lost to outdoor environment.

Figure 8-12 show the temperature change of each room cause by pipe heat loss. In Figure 8, it shows each room temperature differences when there are pipe in back balcony or not. Comparing the red curve and the black one, we can see, when pipe is in back balcony, then temperature in back balcony increases about 0.5 ℃, while others do not show so much difference. The same situation when pipe is in living room, room 1, room 2 and front balcony show from Figure 9 to Figure 12. The biggest difference is when pipe in room 2, the difference can reach 1 ℃.

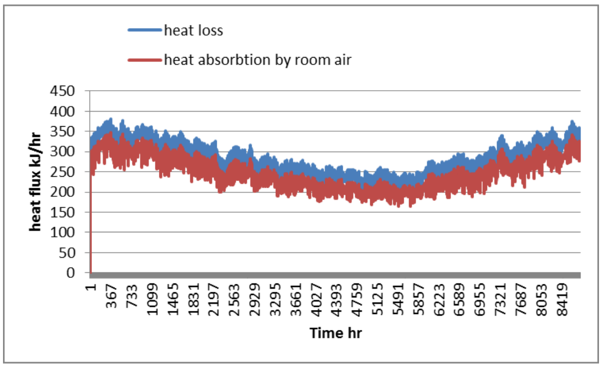

Figure 7 heat loss whereabouts

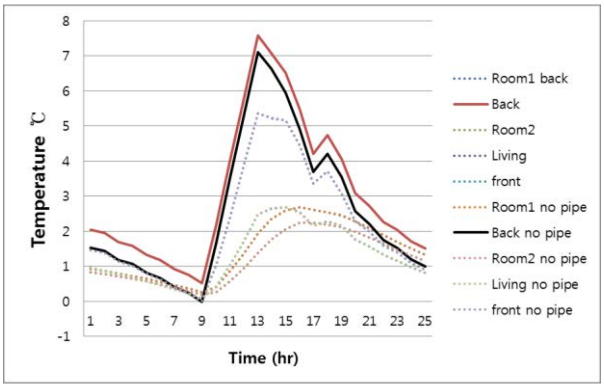

Figure 8 Temp. difference when pipe in back balcony

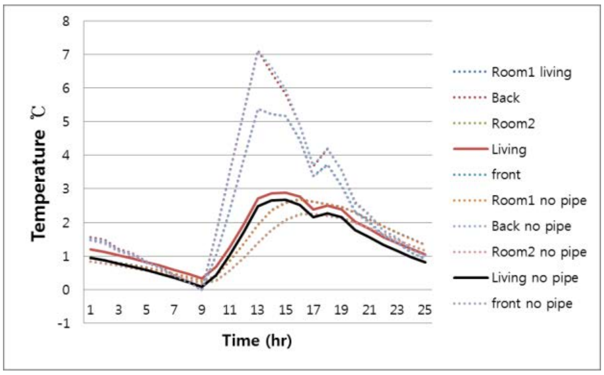

Figure 9 Temp. differences when pipe in living room

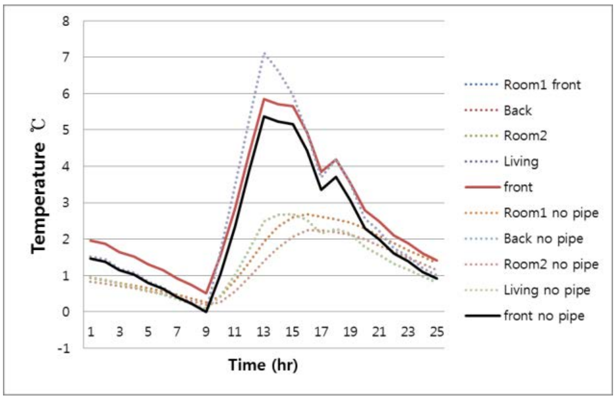

Figure 10 Temp. differences when pipe in front balcony

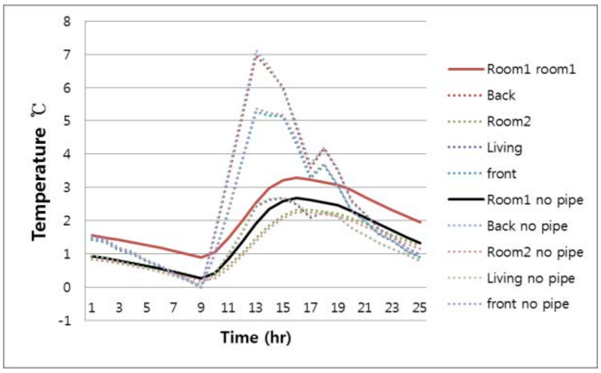

Figure 11 Temp. differences when pipe in room1

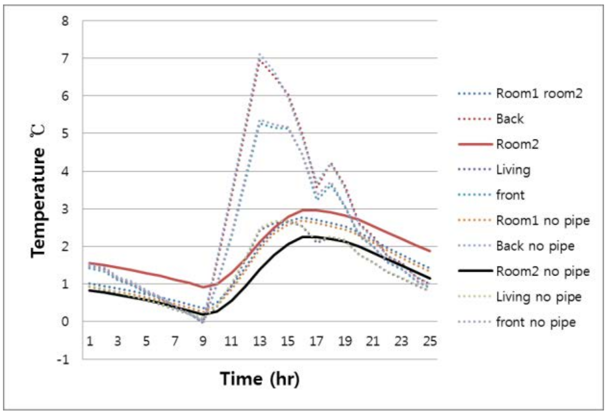

Figure 12 Temp. differences when pipe in room2

CONCLUSION

The optimization and comparative studies of the domestic hot water pipe system are performed in this paper. The results can be used for design guidelines, simulation and experiment studies of the compound heating device. Preliminary conclusions can be drawn as follows:

1. Pipe duct is set in washroom in this paper, so we give three different washroom locations to analyze the different pipe influence on room thermal behaviour. Washroom temperature and building heat load are first analyzed and the simulation results show that under cold area like Seoul, pipe locate next to east external wall can bring biggest benefit to building room temperature and heat load. Also a position factor is proposed as a criterion to evaluate pipe position influence in this part.
2. Other factors can affect heat loss in different location are also taken into consideration. The results show position factor grows proportionally with water temperature and during fall season building get most effective heat loss from pipe.
3. Furthermore, in order to know heat loss whereabouts and influece on temperature, another single house building with five zones were simulated, and the results show pipe heat loss mainly can only affect the room where pipe locate in, only few of heat can transfer to other zones or outside through walls. About 85% heat loss from pipe is absorbed by room air and around 15% are absorbed by walls and windows through long wave radiation. The room temperature difference caused by pipe location can be as big as 1℃.

NOMENCLATURE

$\dot{G}_{ir}$ = long wave radiation between wall and walls or windows
I = identity matrix
F = view factor
ρ_{ir} = reflectivity diagonal matrice
ε_{ir} = emissivity diagonal matrice
$\dot{Q}_{surface,pipe}$ = total heat loss from pipe surface
$h_{outside}$ = the natural convective heat transfer coefficient
SA = the surface area of insulation
T_j $[°C]$ = outside surface temperature of pipe insulation
$T_{env}[°C]$ = environment temperature

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