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Thermal Radiant Cooling System Using Recycled Water from Swimming Pool

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Global warming has an impact on the high room temperature, that can cause excessive use of air conditioning (energy). This directly give contribution not only on the high electricity usage but also energy consumption which is related to the decreasing environmental quality (greenhouse gases emission). In this study, the main concern is to see the potential in maximizing the role of recycled water as air conditioning elements for cooling system. The recycled water referred to this study is the used water originating from the swimming pool area, in which the pool itself acts as a part of the recirculating water system. The system consists of pipe grids in different lengths and widths in suspended ceilings or concealed has possibility to adjust the heat radiation from tempered walls directly to the room. The pipe grids itself serves as a cooling agent. This research was conducted adopting basic equations for radiant heat transfer, the equations makes it easier when application in the field so it can be used to determine the cooling effect produced. Calculation method conducts analysis to the surface of the panel which was exposed to the radiation load which would then be transfered by recycled water from swimming pool. The calculation method obtained through this study is expected to be used as a reference in recycled water for the cooling system to the room. An assumption calculation is done to see the potential of the radiant panels surface cooling efficiency, particularly by looking from the pipe type variable aspect that showed Copper with a surface cooling efficiency value of 3,080 should be used as pipe type for future research with purpose to achieve a higher surface cooling efficiency without cost limitation. This research was carried out by adopting various methods that can overcome ecological problems so that the results will not only provides comfort for the user of the room, but also as a reference for environmentally friendly building designs.

1. Introduction

In Indonesia, there has a been a 97 % increase in total waste water discharge in the last 20 y (1989-2010) (Said, 2017). About 70 % of the total wastewater discharge comes from domestic use. By the increasing of wastewater discharge, means that the water needs are fulfilled but in fact more than 27 M citizens experiencing clean water crisis (Rakhmat, 2018). Since there are many ways of reusing, treating or regenerating wastewater to reuse it which can reduce the consumption of freshwater, the development of technology for freshwater demand is crucial to assess alternatives (Tudor and Lavric, 2011). One way to utilize wastewater is by using pool wastewater by directing it as recycling water for the cooling system. this is not only ecological for the water cycle but also reduces energy use both in housing or commercial facilities, where the Indonesian household sector accounts for around 15 % of total energy consumption in 2018 (Ministry of Energy and Mineral Resources Republic of Indonesia, 2018). About 49 % of the energy consumption in Household sector are from the electricity usages such as Lightings, Electronics, and mainly air conditioning (Heating, ventilation and air conditioning/HVAC). Reducing the energy usage for HVAC will certainly impact greatly on the total energy consumption from residential sector. Utilizing greywater as a cooling system water recycle to decrease energy use goes hand-in-hand with the criteria of a Green Building. Particularly in the subject area of energy efficiency and water efficiency (US EPA, 2018). The challenge itself in the usage of HVAC in transporting heat within a building is the usage of air volume as a variable and the energy usage in heat exchange process night cooling by ventilation or solar heating is used rather than using

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chiller. Almost none of the previous studies regarding thermal radiation cooling system has utilize water recycle from water catchment area (open water tank or swimming pool) as a source of cooling system. The objective of the study is to evaluate the basic design calculation of using water recycle and recirculation from a water catchment area or tank, in this case is a swimming pool as an alternative source of cooling system, which is Thermal Radiation Cooling System. This study could help fill in research gaps as a guide to use thermal radiation cooling system by recirculation using water from water catchments unit (swimming pools and/or open water tanks).

2. Literature review

The effects of global warming are causing heat risings in places all over the world especially in tropical countries such as Indonesia, this leads to the need of cooling technologies for public, private and residential buildings is deeply needed. Cooling is the service of providing low temperature media and at the same time energy (heat) is transferred to other media, this is the reason cooling is always associated with heat transfer (Rutz et al, 2017). There are also cold storage technologies that is used to produce cooling while the production conditions are as effective and favourable as possible. There are two types of cold storage for prolong period of cold storage facility (refrigeration system) and dedicated production of ice or cold water stored in a vessel. In which, both types consider temperature greatly (Rutz et al, 2017). Recycled water has also been used for cooling technology, more commonly for cooling towers or air conditioning water condensation. There has been little studies or application of recycled water for residential cooling system purposes. Using recycled water for radiant cooling ceiling will be both financially and environmentally friendly. The water circulation through the adjacent building surfaces in Radiant Conditioning, provides more than 50 % of the sensible heat flux of the building conditioning by thermal radiation and the rest is by convectional heat transfer (Feng, 2014).

The main reason why using radiant systems can reduce energy consumption is the utilization of heat transport by water circulation as to air circulation. In this study, the water circulation used is recycled water from the swimming pool drainage area in which it acts as a water recirculation system as well. The radiant cooling system used in the study consists of pipe grid in different lengths and widths in suspended or concealed ceilings, the pipe grids recirculate recycled originating from the pool drainage area. This research is conducted to calculate the cooling effect produced and the radiation load passed by the recirculating water in the pipe grid. For many applications, cooling is needed especially during the warm season when there is intensive solar irradiation. For renewable cooling, there are some technologies can be used such as: Free cooling (commonly used in single cooling sources such as conventional chiller); Conventional vapor compression chillers (use a circulating liquid refrigerant as the medium, most widely used devices for air-conditioning in buildings and cars); Absorption chillers (use a heat source, , as main energy for the cooling process); Adsorption chillers (use solid sorption materials instead of liquids); and Desiccant cooling systems (open cycle systems).

The success of this kind of HVAC System is bound to design, comfort, and energetic reasons. The use of radiant panels leads to more free usable net floor space, a typical of cooling air systems, to achieve quite uniform temperatures into the rooms, and to obtain significant energy saving (Causone et al, 2007). Causone (2007) reported that for comfort reason the temperature of panels must not be lower than 292.15 K and must not be lower than the dew point temperature of the room so that moist condensation could be avoided. The most common calculation methods, as the Room transfer functions method, use the concepts of Heat Gain and Cooling Load. Heat gain is the amount of heat gendered or introduced into the room at a specific time T_θ. The cooling load is the amount of heat that must be taken away from the room at the same time T_θ in order to maintain the project conditions of temperature and humidity. The Heat extraction rate is the real heat rate taken away from the room by the plant at the time T_θ (It is linked to the plant inertia)

The use of surface water as cooling water has several consequences, when the heated cooling water is released to the surface water, the temperature water increases (Lenntech BV, 2003). Recycled water could reduce cost needed for the cooling system to Energy efficiency could be achieved as well by substituting the air conditioning system from air conditioning to radiant cooling ceiling panel, in which 80 % of space cooling is conducted via cooling water (Roschmann, 2015). This research focused on calculation method that can be used for the radiant cooling system. The chilled water is produced by the system and heated water will produce in a panel then went back to the pool. The calculation method is governed by the following key factor: The difference of the temperature between supply and return pipes, flow velocity, Grid pressure and pressure differential between supply and return pipes.

3. Methodology

Compared to the air-based conditioning system, a radiant system is unique because it is a case when the HVAC system becomes part of the building elements, and the interactions of the radiant system with the ever changing space thermal conditions become particularly crucial for design analysis and control purposes (Olesen et al. 2006). Overall, there are two heat transfer process involved in the operations, the conditioning space and the radiant layer surface heat transfer and the water loop and the radiant layer heat transfer process. There are many design guidelines related to the design process of radiant systems Some of them provide analysis methods that are generally applicable to all types of HVAC systems, and some of them are dedicated for a specific type of radiant system. They play critical roles by providing guidance to practitioners for load analysis, system performance testing, and modeling. This part offers an overview of using water recycle as source of the cooling system, the swimming pool mention in the design concept acts as the water catchment area. The following Figure 1 is a schematic calculation method that will be used in applying water recycle as thermal radiant cooling system.

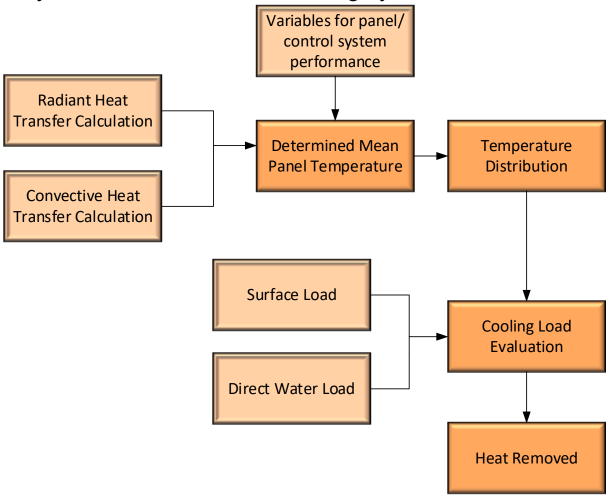

Figure 1: Schematic Calculation Method for Radiant Cooling System

From the schematic calculation shown in Figure 1, the equation used for determining radiant heat transfer is derived from the Stefan-Boltzmann Equation and resulting in Eq(1) (ASHRAE 1996):

$$q_r = 0.15 \times 10^{-8} \left[(t_p)^4 - (AUST)^4 \right] \quad (1)$$

In where q_r is radiant cooling (W/m^2), t_p is mean panel surface temperature (K) and AUST is the area weighted average temperature of the non-radiant panel surfaces of the room (K). Time (T_x) is in min and temperature are in K. The equation for cooling convective heat transfer or q_c is shown in the following Eq(2) (ASHRAE 1996):

$$q_c = 0.31(t_p - t_a)^{0.31}(t_p - t_a) \quad (2)$$

In where, t_a is the area weighted average temperature. Because thermal radiant cooling system works both by convection and radiation, by combining the result of Eq(1) and Eq(2) the heat transfer coefficient could be acquired. Based on the research conducted by Conroy and Mumma (2001), seen that greater heat transfer is achieved by the greater the difference between the mean temperature and the temperature of the room panel. transfer. In addition, from the study also known that even though the radiant heat transfer is highly nonlinear, overall heat transfer coefficient in the temperature range of 283.15 - 291.15 K is relatively constant. The mean panel temperature needs to be determined prior and the temperature distribution in the direction of flow which is the mean radiant panel temperature could be known. Variables needed in knowing the performance of the panel or control system include, pipe diameter, discharge per panel, pipe length, distance between pipe middle, panel area, panel material thickness, inlet temperature, room temperature, overall heat transfer coefficient, pipe arrangement. After all the steps has been done, then a cooling load analysis method can be done. The purpose of conducting a cooling load analysis is to support the sizing of HVAC equipment. In the case of radiant systems, it is used to determine the required cooling output of the radiating surface. Considering the fact that this study is a method concept study and no pilot project has been done. Only a calculation of possible surface cooling efficiency or $q_{SL}^{\cdot}$ could be acquired using the appropriate assumptions by first calculating the heat power removed by the panels surface or surface load or Q_{SL} can be evaluate using the following simplified Eq(3):

$$Q_{SL} = k \cdot A \dot{\cdot} (T_{sp} - T_{air}) \quad (3)$$

Where, T_{sp} is the Temperature of panels surface,k is surface conductance that varies based on the material type as shown on Table 1 column 2 and A is the panels surface area in m^2. The surface cooling efficiency or or $\dot{q_{SL}}$ can then be calculated by the following Eq(4):

$$\dot{q_{SL}} = (\dot{Q_{SL}}/A) \quad (4)$$

Surface cooling efficiency itself accounts for the reduction in temperature potential between the panel surface and the ambient. In studying cooling system, Room transfer functions method is the most common calculation methods that uses concepts such as Heat gain which is the amount of heat gendered or introduced into the room at a specific time T_θ, Cooling load which is the amount of heat that must be taken away from the room at the same time as T_θ, in to maintain temperature and humidity and lastly is Heat Extraction Rate which is the real heat rate taken away from the room by the plant at the time T_θ, although it is not relevant in calculating design peak cooling load, it is taken out of the calculation study (Causone et al, 2007). In calculating and evaluating the cooling load needed, Direct water load and surface load must be calculated and studied further also.

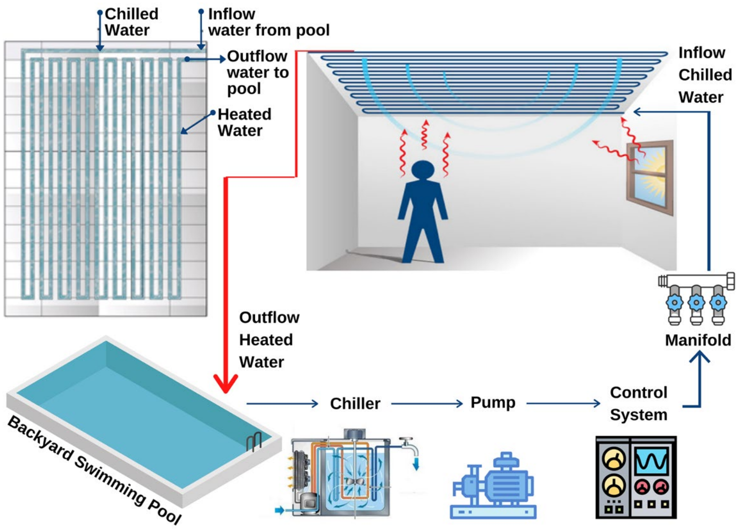

Figure 2: Possible ceiling radiant cooling panel layout for a 41.25 m^2 room

The research concept is explained in Figure 3 where the main source of water originates from the water catchment area which in this study is an open swimming pool water. From the swimming pool it will be transported to a chiller which is used to cool the fluid medium to required temperatures and will go to through the manifolds by going through a pump and control system prior. Control system may be used to regulate conditions using inputs from various sensors installed in the room. The chilled water going through the manifolds will then be distributed to the grid pipes in the ceiling. The chilled water in the pipes will absorb heat from the ceiling and room to making it cooler than the objects and occupants in the room, resulting in a temperature difference and will ensure heat from the bodies will be radiated toward the building's cooling component and resulting in thermal comfort to occur in the room. The water going out from the grid pipe ceiling will be warmer and sent back to the manifold and back to the chiller and pool, creating a cycle utilizing recycled water from the pool and make water in the pool warmer. It can also be seen from the energy savings that made from radiant heat transfer. The use of Air Conditioner will certainly be reduced since the temperature in the room will become lower. Naturally, the average swimming pool has a temperature range of 298.65 – 300.95 K, but due to the possible temperature change, the utilization of a chiller unit would be much safer to keep the temperature of the chilled water stable. The pool itself has a volume of 38.45 m^3 or 38,454 Litres. In this study, the size of the pool does not matter, what is important is the volume of water that will be used. The pool itself only serves as a water catchment or water storage. The water flow through the pipes will be kept at 65 L/min based on the pipe size that will be used which is 1" (Poerbo, 1999). For the pipe type itself, polybutylene piping is already widely used for Radiant Cooling Ceiling by RDZ Australia (Thermo Hydraulic Wholesaler), but by considering material, sizing, and thermal conductivity for the panel of PVC, brass, copper, or aluminium can be used to reduce heat from the environment. The room that will be installed with the pipe grid ceiling is a room with a size of 5.5 m x 7.5 m, a surface area of 41.25 m^2. An example of how the possible ceiling radiant cooling panel layout is shown in Figure 2, the layout shown is designed according to the 41.25 m^2 ceiling used in the study based on a 94 m^2 open office plan example derived from an article in a journal (Conroy and Mumma, 2001).

4. Discussions

Ceilings heights could be important issues and the cooling panels installed could be used so that the ceiling heights could be raised to a certain level, which is architecturally more pleasing (Conroy and Mumma, 2001). The fluid flowing in the parallel tubes increases in temperature exponentially as the panel removes heat from the cooled space, vice versa. Displacement ventilations are normally utilized with Radiant cooling panels, where the ventilation air is a means to replace the existing air with it natural flows through the room (Kulhari et al., 2016). Radiant cooling systems are usually hydronic, cooling using water running in pipes in thermal contact with the surface. Typically, the circulating water only needs to be 2-4 °C below the desired indoor air temperature (ASHRAE,2004). Heat is removed by water flowing the panels of pipes on the ceilings or walls, replacing the cooler water in pipe to the warmed water when it comes out.

With an assumption of Mean Panel temperature of 20 °C (293.15 K) and room temperature of 28 °C (301.15 K), a surface area of 41.25 m^2. Using Eq(3) a surface load for a range of room temperature is acquired and using Eq(4) is used to acquire the surface cooling efficiency. Considering the material availability, PVC Type of pipe is used for this concept with surface conductance 0.19 W/m K. The thermal conductivity (k) of different type of pipe material used in Table 1 is reference from CRC Handbook of Chemistry and Physics as an example to show the comparison in surface cooling efficiency.

From Table 1, it can be seen clearly that the surface cooling efficiency by using radiant cooling system that will reduce effectively the used of air-conditioning system since cooled ceilings operate at relatively high temperatures based on other research (average surface temperature of 29 °C . The radiant cooling system can operate at higher temperatures resulting in an increase efficiency and reduction in energy costs. Radiant panels can be used as both heating and cooling system and can be fitted into the ceilings or even walls. Concerning the calculation method shown before, Table 1 is derived from Eq(3) and Eq(4) with assumed values as a means to show the difference in surface cooling efficiency caused by pipe type. The cooling power of the panels depends on the panels surface temperature, so that the amount of load removed by the panels surface depends on heat exchanges between room air and panels surface temperature. The effect of surface conductance is important for design aspects, because the value greatly affects temperature for cooling or heating efficiency. Another calculation is needed to calculate the panel surface's temperature as it exchanges heat with the water pipe, to find the surface cooling efficiency of the panel surface directly to the air in the room. Table 1 is done to show the potential of cooling efficiency of the cooled water pipe system itself. Thermal conductivity of Copper is very high that means Copper has a good heat transfer of fluids in the panels. Looking at the Table 1 shown above, it could be seen that the types of pipe used matters greatly to the surface cooling efficiency produced. It is shown that copper type pipes have the best surface cooling efficiency out of all the other pipe type. Although thermal conductivity of PVC and Brass are lower than others but due to higher cost and material availability the upcoming research will use PVC and Brass as the panel system. The calculation method could be used globally and so does the thermal conductivity is universal. Temperature varies based on the specific condition. The calculation done in Table 1 used assumptions as a means to show the possible surface cooling efficiency based on the pipe type used.

Table 1: Surface load and surface cooling efficiency assumption for radiant cooling ceiling model concept

Pipe Type	k (W/m.K)	A (m^2)	T_{sp}(K)	T_{air}(K)	Surface Load (W/m)	Surface Efficiency	Cooling
PVC	0.19	41.25	293.15	301.15	86.63	2.14	
Brass	109	41.25	293.15	301.15	35,970	872	
Aluminum	205	41.25	293.15	301.15	67,650	1,640	
Copper	385	41.25	293.15	301.15	127,050	3,080	

5. Conclusions

The results in this paper demonstrate the surface cooling efficiency based on concept and basic formula in regards of the pipe type. For higher level of surface cooling efficiency copper material should be used as pipe type for future researcher wanting to achieve a high surface cooling efficiency without cost limitation. For this result of radiant cooling concept must be adapted to condensation of air moisture on the panel and cooling capacity per area especially in hot and humid climate. It also needs to be noted that not every house in Indonesia has a swimming pool, specific volumetric adjustment needs to be made for additional water catchment tank for applications in various houses or buildings conditions. There is a fair opportunity for energy conservation for houses or buildings, which can be studied further in future research. Future work and research need to explore and to be done in order to get the best results of the efficiency, both in terms of cooling systems, energy efficiency and cost comparisons. Pilot project also must be done to calculate effectiveness of energy saving by using radiant cooling ceiling.

Acknowledgments-

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