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APPLICATION OF NANOFLUID IN HEATING VENTILATION AIR-CONDITIONING AND REFRIGERATION SYSTEM- A REVIEW

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Abstract

In recent years, nanotechnology has attracted much interest for improving heat transfer, refrigerant efficiency (both primary and secondary), and coolant efficiency and heat transfer capabilities in HVAC industry. The nanofluid also improves the efficiency of heat exchangers on both the air and liquid sides, such as condensers and evaporators, as well as heat recovery systems of the HVAC industry. This paper summarises recent advances in nanofluid research and its applications in heat transfer fluids such as primary and secondary refrigerants, coolants/lubricants, and in heating systems. Colloidal mixture of primary and secondary refrigerants with nanoparticle enhance the coefficient of performance because of its high transfer coefficient and a safe working capacity. In addition, studies on refrigeration, air-conditioning with primary refrigerants, air-conditioning with secondary refrigerants, and heating systems have been summarised.

Keywords: Nanofluids, Nanorefrigerant, Refrigeration system, Air-conditioning system, Heating systems

Introduction

The introduction of nanoparticles increases the surface to volume ratio and refrigeration effect of any fluid. [1]. The global primary energy demand is predicted to rise by 30% by 2040. Heating, ventilation, and air conditioning (HVAC) power consumption comprises of major part of industrial and commercial buildings total power consumption. In both buildings and process industries, HVAC systems require a large quantity of energy. As a result, there is an equal chance of large energy savings [2]. The Coefficient of Performance (COP) is a measurement of how effective a heating and cooling system is. The ratio of refrigeration effect to work consumed by the system is the Coefficient of Performance (COP). The COP value is essentially determined by heat extraction at low pressure, heat rejection at high pressure, and the compressor's work consumption [3]. To improve the coefficient of performance, refrigeration effect must be increased while compressor work must be reduced [4]. The performance of an HVAC system can be increased by modifying the equipment design or increasing heat exchange.[5]. Many studies have demonstrated that thermal properties magnifies by inserting nanoparticles in the base fluid [6]. Due to heat transfer augmentation capabilities, the use of nanofluid as primary and secondary refrigerants enhances performance and reduces system size [5].

Nanofluids are nanoparticle suspensions in liquid with a primary dimension of less than 100 nanometers [7]. A nanofluid with greater thermal conductivity than regular fluids is developed by a two-phase colloidal system containing nanoparticles and a base fluid [8]. Nanofluids are suspensions of oxides of metals, fullerenes, ceramics and carbon nanotubes in base liquids such as water, ethanol, brine solution, refrigerant, oil, and lubricant, among others [9]. Application temperatures of Water-based nanofluids restricted to 0 ^{0}C to 100 ^{0}C. Oil-based nanofluids offer a far wider application temperature range than water-based nanofluids [11].

Due to their improved thermal properties, nanofluids given significant promise as coolants in different secters [12]. The size and form of a particle influence its mobility. Nanoparticles have a far larger surface area than microparticles and stay suspended for much longer. Nanoparticles have a 1000-fold greater surface-to-volume ratio than microparticles [13]. Nanoparticles have a large surface area, which helps nanofluids conduct heat better [14]. The thermal properties of nanofluids, as well as their suspension stability and dynamic thermal interactions, are influenced by the size of nanoparticles [15]. Metals (Au, Ag, Cu, and Fe), oxides (CuO, Cu2O, Fe2O3, Al2O3, SiO2, and TiO2), carbon nanotubes (CNTs), carbides, and Si compounds are examples of nanoparticles. Water, refrigerants, ethylene glycol, and oils are some of the base fluids used [13].

By distributing nanoparticles in a base fluid, nanofluids are created. Nanoparticles are subjected to electric potential (Zeta Potential) due to asymmetrical molecules of base fluids. The electrostatic forces in nanofluids are measured using the zeta potential. The consequence of van der Waals and electrostatic forces is responsible for the nanofluid stability and particle agglomeration. The stability of suspension, aggregation, and flow behaviour are all affected by van der Waals forces and electrostatic interactions between particles [16]. Surfactant compounds are frequently employed in the manufacture of nanofluids to avoid particle agglomeration and guarantee that the particles are evenly dispersed throughout the suspension. [17]. Nanofluid is two phase colloidal suspension of single type nanoparticle and base fliud[13]. The colloidal system of two type nanoparticles suspended in a base fluid form the hybrid nanofluid [18].

Nanofluids are prepared by using two different methods. The first is a single-step method, whereas the second is a two-step method [19]. Similarly, blended nanofluids can be made in two ways (a) two different types of nanoparticles added to the base fluid and (b) Nanocomposites are made and then dispersed in a base fluid [20]. In a one-step process, particles are put together in a fluid at the same time. Because this approach avoids nanoparticle aggregation, drying, storage, transportation, and dispersion is reduced and the fluid stability is improved. The one-step approach has a drawbacks of leaving residual reactants in the nanofluids and a high cost The most extensively used approach for producing nanofluids is a two-step process[21]. To generate dry powders of nanoparticles, nanofibers, and nanotubes for this procedure, chemical or physical processes are used. This manufacturing process is both low-cost and large-scale production process. The drawback of the two-step is nanoparticle coagulation. The stability of nanofluids is crucial for their correct performance in heat transfer The concept of nanofluid in HVAC and R system mostly used by researchers because of enhancement of thermal conductivity campared to conventional fluid [13]. Ajayi et al. [22] investigated the conventional VCRS performance with R134a/Al2O3 nanofluid and found the improvement of refrigeration process efficiency and nanolubricants impact on energy consumption ability. Sharif et al. [23] carried out the experimental study of air conditioning system of car by using Sio2/PAG nanolubricant and reveal that the maximum COP increases by 24% and average COP by 10.5%, respectively. F. Ahmed [24] experimentally investigated secondary fluid in refrigeration system made of Al2O3 and water nanofluid and result indicated that at an inlet temperature of 40°C, coefficient of performance was 6.5 with a flow rate of 80g/s, and 15 % volume fraction.

This paper covers review of latest researches on the use of nanofluid in HVAC&R application as thermofluid in the escalation of heat transport, reduction of equipment size and reduction in energy consumption. explore on the subject relevance of nanofluid in refrigeration system, direct expansion air-conditioning system, airconditioing system with secondary refrigerant and heating system are reviewed. The review done in this work is summarised in Tables 1–4.

Nanofluid Application

The review on nanofluid, nanorefrigerant and nanolubricants are classified into four sections. Explore on the subject relevance of nanofluid in refrigeration system is review under first section whereas second and third section concerns the review on research in application of nanofluid in air-conditioning system with primary refrigerant and secondary refrigerant. Researches on the subject application of nanoflud in heating are review under fourth section.

Nanofluid application in Refrigeration system.

D. S. Kumar & Elansezhian [25] looked into the signification of R134a VCRS with 0.2% volume concentration of Al2O3-PAG oil as nano-refrigerant for different mass charge of 134a (150gm., 180 gm. and 200gm.). The results showed reduction in 10.32% energy consumption. Coumaressin et al. [26] examined feature and record of refrigerant-based nanofluid flow through a VCR system. They combined nano particles oxides of aluminium, copper, titanium, and zinc with the basic refrigerant R1234yf with concentration of 0 to 1% and analysed with TK Solver. According to the experimental results the effect of nanorefrigerant is better as campare to pure refrigerant and also aluminium oxide nanofluids showed a 28% higher COP and a 7% lower power consumption against other nanofluids. Chauhan et al. [27] experimentally studied an ice plant test rig. They use a nanolubricant (POE/TiO2) and nanorefrigerant (R134a & TiO2) of different volume concentration.. Refrigerant properties came by REFPROP 9.1 programme. They used a mixture of R134a and a nanolubricant (POE/TiO2). The compressor's input power was lowered by 15.7%. The system COP increased by 29.1% at 0.2% TiO2 concentration. Sheng shan Bi et al.[28] were examined the reliability and performance of a residential refrigerator employing a lubricant containing TiO2 nanoparticles and mineral oil in R134a refrigerant with 0.06% and 0.10% mass fraction of TiO2+MO. The findings show that R134a and nanoparticle-enhanced mineral oil was suitable for refrigerator normal and safe working. Their output was superior to that of R134a and POE oil. They also discovered that using 0.1 % TiO2 Nanoparticles reduced energy consumption by 26.1% when compared to R134a and POE oil systems. Krishna Sabareesh et al.[29] experimentally explore the consequence of scattering a low volume concentration of 0.005%, 0.01% and 0.015% TiO2 nanoparticles in a mineral oil-based lubricant with R12 as the working fluid. They also measured viscosity and examined at lubricating characteristics to determine the optimal nanoparticle concentration in mineral oil for optimal performance. The result shows that the the average rate of heat transfer improved by about 3.6% as a result of the inclusion of 0.01% volume fraction TiO2 nanoparticles in the lubricating oil, while compressor work decreased by about 11%, the coefficient of performance increasing by around 17%.

Ande et al.[30] concluded the effect of combination of Cuo nanoparticle with R134a refrigerant with concentration 1.6% over a conventional mechanical refrigeration system. Nano fluids improves the heat exchange properties of medium and hence the refrigeration system's coefficient of performance. The study found that employing nano refrigerant CuO-R134a resulted in improved heat transfer characteristics, a 16.6% improvement in COP as compared to R134a, and a 13.79 % reduction in energy consumption.. R. Kumar & Singh [31] were experimentally investigated use of ZnO nanoparticles with the blend of propane and isobutane as the nanorefrigerant in refrigeration system. The compressor lubricating oil was used to add the zinc oxide nanoparticles to the system refrigerant. They observed that evaporator pressure, condenser pressures and condenser outlet temperature were dropped by 17%, 21% and 25% respectively of propane / isobutane refrigeration system with ZnO nanoparticles of concentration 0.2, 0.4, 0.6, 0.8 and 1.0 wt%. They also observed that compressor pressure ratio and compressor energy usage were reduced by 5.76% and 7.48% respectively using propane / isobutane refrigeration system with ZnO nanoparticles. The refrigerant effect was raised by 34%, while compressor energy usage was lowered by 7.48 %, resulting in a 45% improvement in the COP. F. S. Javadi & Saidur [32] evaluated the energy savings, cost savings, and ecological consideration of employing nanofluid in a residential refrigerator. They investigate the influence of using nanofluid in residential refrigerators on energy savings and look into ways to reduce carbon emissions from an ecology aspect. TiO2 and Al2O3 nanoparticles of various mass fractions added to R-134a. The results indicated that among different nanofluids, the usage of 0.1% TiO2–mineral oil–R134a nanorefrigerant resulted in a greatest energy savings of 25% and 0.06 % TiO2 has a stronger effect than 0.1 % Al2O3. Soliman et al.[33] evaluated experimentally a vapour compression cycle with nanofluid in the primary refrigeration loop (R-134a) and 20 L of water as a cooling load. They employed Al2O3 nanoparticles in lubricant compressor oil of convetinal refrigeration cycle. They found that Al2O3 nanoparticles along with refrigerant and lubricant oil improve vapour compression cycle performance theoretically by 22.5% and actuality by 10%, and reuction in energy usage by 10%. According to the data, the polyester oil with Al2O3 nanoparticles mixture outperforms Al2O3 nanoparticles mixture by 7.5% in theoretical COP and 19.5% in actual COP. According to experimental results, the theorotical COP of the system increases by 22.49% and actual COP by 10%. They also discovered that utilising nanoparticles reduces energy usage by up to 9.28% and increases coefficient of heat transfere of water by 50%.

Adelekan et al.[34] conducted the experimental study on nanoparticles mixed with refrigerant. They used steady state analysis to analyse the refrigerator's performance utilising test criteria. They observed that 60g of refrigeants (Isobutane) with concentration of either 0.1% or 0.3% TiO2 nanolubricant mixture produced the lowest evaporator air temperature of -15^{0}C, whereas 80g of refrigeants (Isobutane) with pure lubricantl oil produced the highest evaporator air temperature of 80^{0}C. They also discovered that the maximum cooling value was 290.83 kJ/kg for a 40g of Isobutane & TiO2 (0.1% Wt concentration) mixture with a COP of 4.99. Ohunakin et al. [35] used test the performance of a residential refrigerator for Liquified petrolium gas (40g) as refrigerant with nanolubricant. They injected several homogenised nanoparticle of Silicon Dioxide, Titanium Dioxide and Al2O3 with compressor lubricating oil as nanoparticle-lubricant mixtures into the system's compressor. It was concluded that TiO2 and SiO2 nano-lubricants consumed less energy as campared to conventional lubricant with reductions of thirteen percent and twelve percent for TiO2 and SiO2, respectively. They also observed that when compared to conventional lubricant with a COP value of 2.91 at steady state, Silicon Dioxide, Titanium Dioxide nanoparticles with lubricants improved COP values by 2.06%, while Al2O3-lubricant reduced COP values by about 31.96%. Subramani & Prakash [36] carried out a experiment to analyse the output of a conventional refrigeration system for various types of lubricant oil in compressor. The study demonstrated that

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the refrigeration system's freezing capacity was more with SUNISO 3GS + Al2O3 nanoparticles oil mixture than with polyolester oil. The compressor's work required was reduced by 25% by using the nanolubricant instead of standard polyolester oil. They also found that when the polyolester oil is replaced with nanparticle with lubricating oil, the refrigeration system's coefficient of performance rises by 33%. Ajayi et al.[37] used a 0.04% Ni/R134a nanorefrigerant to examine the thermal and retrospective analysis of a external driven conventional refrigeration system. When using solar/battery as a power source, their research found that the conventional refrigeration with Ni/R134a nanorefrigerant gives COP ranging from 7.05% to 14.12%. They also observed that refrigeration system with nanorefrigerant required more work than R134a refrigerating system. Ajayi et al. [22] experimentally conducted performance analyses of a vapour compression refrigerator with Al2O3 nanoparticles distributed in Capella D mineral oil/R-134a as the working fluid. The findings of the thermal conductivity and salinity testing demonstrated that the nanoparticles had a beneficial impact on the nanorefrigerant's thermal performance, while the viscosity tests revealed that the nanolubricant had an impact on the energy consumption ability. The outcome showed that the lower the viscosity, the better the ability to conserve energy and the pH results show that the presence of Al2O3 nanoparticles in the working fluid may have a deleterious impact on the compressor walls and materials. The results also show that as compared to a conventional working fluid combination, the system with Al2O3 nanoparticles dispersed nano working fluid exhibited faster cooling, greater performance, and lower energy usage. Fig 1 shows the performance of the system when using the traditional working fluid (R134a + Capella D oil) versus when using the nanorefrigerant.

Shengshan Bi et al [38] studied the performance of a residential refrigerator employing TiO2-R600a nanorefrigerant as the working fluid in an experiment. It was concluded that 0.1 and 0.5g/L concentrations of TiO2-R600a can save 5.94% and 9.60% energy usage, respectively, as compared to refrigerators employing pure R600a as a working fluid and a nanorefrigerant system's freezing velocity was faster than that of the R600 system. Jia et al. [39] carried out the experiment to analyse the performance of the refrigeratizon system by using two kinds of mineral based nano-oils in a domestic refrigerator compressor. The outcome showed that when nano-oil is utilised for the compressor in R600a refrigeration systems, the COP increases and there is no apparent influence with either of the two types of mineral-based nano-oil in R134a refrigeration systems. They also found that with a COP improvement of 5.33%, the MoFe2O4/NiFe2O4 nano-oil had the greatest impact on the refrigeration performance of a compressor utilising R600a as the working fluid. Farhood Sarrafzadeh Javadi & Saidur[40] experimentally invested the performance of a nano-refrigerant-based domestic refrigerator and the stability of Al2O3 nanofluid. It was concluded that when 0.1% -Al2O3 nanoparticle was introduced to the system, the average temperature gradient increment in the evaporator increased by 20.2%, and the refrigerator's energy consumption decreased by 2.69%. Padmanabhan & Palanisamy [41] examined the ir-reversibility of the R134a, R436A (R290/R600a-56/44-wt.%), and R436B (R290/R600a-52/48-wt. %) working fluids in a vapour-compression refrigeration system (VCRS) using Mineral oil (MO) with 0.1 g L-1 TiO2 nanoparticles mixture as the lubricant.

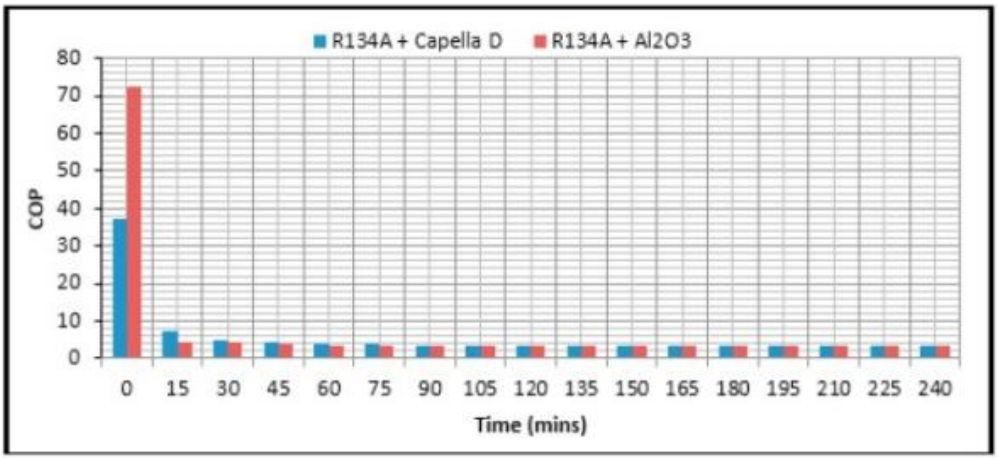

Figure 1. Comparison of the COP [22]

The study demonstrated that the overall ir-reversibility of the VCRS (529, 588, and 570 W) was found to be superior to that of R134a, R436A, R436B, and POE oil systems in various processes (777, 697 and 683 W). The findings also demonstrated that TiO2 nanoparticles can be utilised in VCRS with a reciprocating compressor to significantly reduce the process' irreversibility. Sarkar [42] was examined the impacts of various design and operational factors on system performance enhancement using a nanofluid cooled shell and tube gas cooler for a transcritical CO2 refrigeration system. The results demonstrate that as the compressor discharge pressure, nanofluid mass flow rate, gas cooler length, and volume fraction rise, the cooling COP increases. He also showed that the highest cooling COP improvement of the transcritical CO2 cycle for Al2O3-H2O is 26.0%, whereas it is 24.4% for TiO2-H2O, 20.7% for CuO-H2O, and 16.5% for Cu-H2O.

Nanofluid application in air-conditioning system with primary refrigerant.

Balaji et al.[43] experimentally conducted the performance analysis of domestic air-conditioning system to reduce the compressor

Table 1. Research on the subject application of refrigeration system

Researcher	Refrigerant	Nanoparticle	Lubricant	Nanoparticle mass fraction	Evaluation
Chauhan et al.[27]	R134a	TiO2	Polyester oil	0.1%-0.3% vol %	Results indicate that the COP increased by 29.1% and the compressor's power consumption decreased by 15.7 % at 0.2% TiO2 concentration compared to system using mixture of R134a and lubricant (POE).
Krishna Sabareesh et al.[29]	R12	TiO2	Mineral Oil	0.005%-0.015% vol %	The studies showed that the addition of 0.01% volume fraction of TiO2 nanoparticles to the lubricating oil enhanced the average heat transfer rate by 3.6 % and decreased the average compressor work by 11 %, resulting in a 17 % gain in the COP.
F.S. Javadi & Saidur [32]	R134a	TiO2 and Al2O3	Mineral Oil	0.06%-0.1% wt%	The study indicates that 0.06 % TiO2 has a greater effect than 0.1 % Al2O3. Among different nanofluids, the usage of 0.1 % TiO2–mineral oil–R134a nanorefrigerant resulted in a greatest energy savings (25 %).
Soliman et al.[33]	R-134a	Al2O3	Mineral Oil and Polyester oil	0.05%-0.15% wt%	The results showed that the optimum concentration for nanolubricant is 0.1% wt%. According to the results, the polyester oil with Al2O3 nanoparticles mixture outperforms the mineral oil with Al2O3 nanoparticles mixture by 7.5 % in theoretical COP and 19.5% in actual COP.
Ohunakin et al.[35]	LPG (40g)	TiO2, SiO2	Mineral Oil	Selected Nanolubricant	The results showed that TiO2 and SiO2 nano-

		and Al_2O_3			lubricants have 13 and 12% lower power consumption than the base refrigerant (LPG), respectively. SiO_2 or TiO_2 nano-lubricants improved COP by 2.06%, but Al_2O_3 nano-lubricants reduced COP by 31.96%.
Subramani & Prakash [36]	R134a	Al_2O_3	Mineral Oil and Polyester oil	0.06 %. wt%	The results showed that the compressor's power consumption is reduced by 25% and coefficient of performance increases by 33%, when nanolubricant is used instead of standard POE oil.
Ajayi et al.[22]	R134a	Al_2O_3	Capella D mineral oil	0.5% Wt%	The results show that the nanolubricant has superior thermal conductivity and salinity than the base oil, demonstrating that it can transmit heat more efficiently (Capella D). Furthermore, the findings of the viscosity test revealed that the presence of nanoparticles reduced the viscosity of the lubricant, implying a reduction in energy consumption.
Shengshan Bi et al.[38]	R600	TiO_2	Mineral Oil	0.1-0.5% wt%	The results showed that TiO_2-R600a concentrations of 0.1 and 0.5g/L can save 5.94% and 9.60% of energy, respectively, when compared to refrigerators that use pure R600a as a working fluid.
Jia et al.[39]	R134a & R600	$MoFe_2O_4/NiFe_2O_4$	Naphthenic mineral oil B32	0.8075 vol%.	The results showed that the $MoFe_2O_4/NiFe_2O_4$ nano-oil had the greatest impact on the refrigeration performance of a compressor using R600a as the working fluid, with a COP improvement of 5.33%.
F.S. Javadi & Saidur	R134a	Al_2O_3	Polyester oil	0.05%-0.3%	The results showed that when 0.1% Al_2O_3 nanoparticle was added to the system, the refrigerator's electricity usage was 2.69% lower than that of the basic

fluid (R134a) and there was a 20.2% increase, at the evaporator's temperature gradient.

load with Al2O3 nanoparticles of different volume Concentrations as a shell-side base fluid in intercooler. It was concluded that when compared to the case without the intercooler, the base fluid had a COP increase of roughly 31% and the 0.75% nanofluid had a COP increase of 49.32% with a flow rate of 2 LPM. In addition, a 12.24% reduction in power consumption was noted. The performance coefficient of a thermosyphon heat exchanger (THE) evaporator portion that functions as a pre-cooler and a condenser section that works as a reheating coil was experimentally tested by Firouzfar et al.[44], utilising methanol and methanol-silver nanofluid as working fluids. The experimental results showed that using pure methanol as the working fluid, energy savings ranged from 3.5 to 25% for cooling and 13 to 80% for warming supplied air. If methanol-silver nanofluid was used in the same THE without altering the other parameters, energy savings for cooling and reheating increased by 8.8-31.5 % and 18-100%, respectively. It was also discovered that the THE's condenser could be utilised as a reheater to replace the traditional reheating coil in situations where air supply was required above 400C DBT. The usage of nanofluids as a fluid in an air conditioning system was examined by Shanmugasundaram & Elansezhian [45] and a computer simulation tool was constructed to solve the nonlinear equations of the system model. The introduction of nanofluid as a fluid in VCS boosted system performance from 12% to 18% for the same geometric parameters of the system, according to simulation data. They also investigated the performance of refrigeration system with R22 and 0.1% v of three types of nanofluids namely (CuO, ZnO, Al2O3). The results indicates that COP of refrigeration system with CuO nanofluid equal to 5,26 was higher than other. Husainy et al. [46] were investigated performance of the of ducted air conditioning system with pure POE oil and then specific concentration of 0.25%,0.50%,0.75% and 1% (by Mass fraction) of CuO nanoparticles were added in POE oil (polyolester oil). The study demonstrated that in comparison to a traditional system, the compressor work was reduced by 21.37%, while real COP, theoretical COP, and carnot COP were increased by 26.92%, 4.45%, and 7.6%, respectively. The addition of 1% CuO Nanoparticles to compressor oil (POE oil) improves the overall performance of the ducted air-conditioning system when compared to pure compressor oil, according to the findings.

Park & Jung [47] investigate the impact of 1.0 vol.% carbon nanotubes (CNTs) on overall heat transfer performance in nucleate boiling of R123 and R134a, two common refrigerants used in building chillers for air conditioning. The results indicate that the heat transfer enhancement was up to 36.6% at low heat flux for two refrigerants R123 and R134a. Due to aggressive bubble formation, the augmentation reduced as the heat flux surged. Altohamy et al. [48] evaluate the impacts of heat transfer fluid (HTF) temperature, volume flow rate of heat transfer fluid (HTF), and additive quantity of aluminium oxide (Al2O3) nano particle on the time of complete charging (solidification) processes, solidified mass fractions, percentages of energy stored, and charging (solidification) rates for thermal storage systems in an experimental investigation. Thermal storage systems play a vital role in central air-conditioning in the large buildings, high powered electronic cooling applications, and various industrial process cooling applications. The experiments were conducted with pure water and the NFPCM with volumes fractions 0.5%, 1%, 1.5%, and 2%. The results show that At HTF intake temperature of 12 oC, the percentage reduction in complete charging time was approximately 32%,, 28%, 18%,, and 12%, at HTF volume flow rates of 12, 10, 8, 6 lpm, respectively. F. Ahmed & Khan[49] explored the use of Al2O3 and Cu nanofluids in an external cooling jacket for the condenser part of an air conditioner for three volume fractions of 1%, 2%, and 5% with water as the base fluid. Experimental results indicate that Al2O3 nanofluid increased the COP by 22.1% at the greatest volume fraction of 5%, while copper nanofluid increased the COP by 29.4%. Figure 2 shows the performance of a VCR system with water, Al2O3 nanofluid, and Cu nanofluid in the condenser jacket.

Abbas et al. [50] investigated the performance improvement of the CNT-based nanolubricant in the refrigeration system with a concentration of 0.01-0.1 wt% of CNT Polyester Oil along with environmental friendly refrigerant R134a. It was shown that adding CNT nanoparticles to POE lubricant improves the refrigeration system's coefficient of performance (COP), with the greatest COP value of 3.757 at 0.1% CNT. Hussen [51] was tested and compared the performance of refrigerant R22 without nanoparticles and with nanoparticles in a window type air-conditioning system for TiO2 nanoparticles as a lubricant-additive for a Compressor of Window Type Air-Conditioner System. The experimental results demonstrated that R22 with nanoparticles has a higher COP than R22 without nanoparticles, ranging from 7.93 to 11.99%.

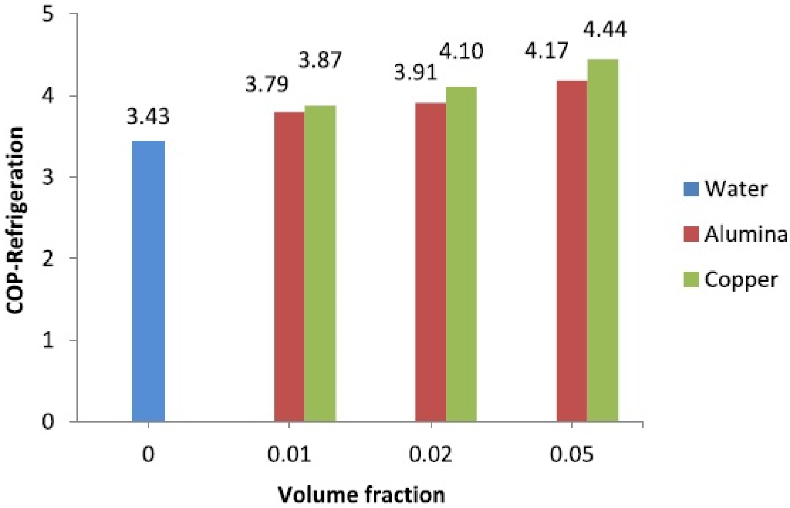

Figure 2. shows Variation of COP of air conditioning system operating with water, alumina nanofluid, and copper nanofluid [49]

Chandraprabu et al.[52] used the condensing unit of an air conditioner to evaluate the heat transfer performance of nanofluids (Al2O3/water and CuO/water nanofluid) by suspending nanoparticles of 30 nm in the base fluid at varied volume concentrations (1%, 2%, 3%, and 4%). The outcome showed that the heat transfer coefficient of Al2O3/water nanofluid increased by 49.84%, whereas the heat transfer coefficient of CuO/water nanofluid increased by 58%. The Nusselt number for Al2O3/water nanofluid was increased to 33.86%, and the Nusselt number for CuO/water nanofluid was enhanced to 39.48%. CuO/water nanofluid has a higher convective heat transfer coefficient than Al2O3/water nanofluid, according to a comparison of the two working fluids. Colangelo et al. [53] conducted a performance study of an HVAC system of an educational building in the university campus of Lecce, Italy using a water-glycol nanofluid with Al2O3 nanoparticles, evaluating all energy fluxes in order to study, analyse, and quantify the efficiency of the system and to evaluate its transient and average performance using the simulation software TRNSYS 17. The results revealed that using a nanofluid based on a water-glycol mixture and alumina enhances efficiency by around 10% while lowering the HVAC system's electrical energy consumption. Sharif et al. [23] experimentaly investigated the performance of automotive air conditioning system operating with SiO2/PAG nanolubricant by analysing heat absorb, compressor work and coefficient of performance (COP).

The study demonstrated that For SiO2/PAG nanolubricants, the maximum COP enhancement was recorded at 24%, with an average of 10.5%. and For all compressor speeds, the COP was maximum at 0.05% volume concentration. The performance of a solar-powered air-conditioning system employing SWCNT/R407c nano refrigerant, as well as using both passive elements in an HVAC system, was investigated by Rahman et al.[54]. The results shows that the SWCNT/R-407c nanorefrigerant demonstrated potential improvements in thermophysical characteristics and overall system performance when compared to the base refrigerant R-407c and the Al203/R134a nanorefrigerant. The outcome showed that the cooling load was lowered by 31.5% because to the contributions of passive measures such as trees, double-glazed windows, roofing reflecting material, and overhang and the use of nanoparticles reduced the compressor's consumption work input by around 202.56 W with the overall system performance increased by about 5%. Zaid A. Shaalan [55] the performance of an air conditioning system by adding Al2O3 and TiO2 oil nanoparticles to the compressor lubricating oil at different weight concentrations ranging from 0.1 to 0.5 %. The experimental results reveals that the use of Al2O3 and TiO2 in cooling oils lead to energy savings of around 32.5% at 0.005 fractions of mass and 24.3 % at 0.001 fractions of mass, respectively when compared to the natural system.

Nanofluid application in air-conditioning system with secondary refrigerant.

Mahdi et al.[57] conducted an experiment to improve the performance of a water chiller system by using nanofluid (water+TiO2) in the shell side of the chiller at various volume concentrations (0.05 % , 0.075 % and 0.1%) and two alternative refrigerants (R-407c and R-134a). The sdudies shows that the COP of a refrigeration system using R134a is around 28% higher than the COP of the identical system using R407c. Sunu et al.[58] conducted An experimental investigation for heat transfer enhancement by Alumina-water nanofluid, effectiveness (ε) and overall heat transfer of fan coil unit (FCU) of water chiller AC with 0.2% nanoparticles added to chilled water. The study demonstrated that the heat transfer increased as the mass flowrate of chilled water increased. At a specified mass flowrate, the heat transfer enhancement of nanofluid chilled water is

Table 2. Research on the subject application of air conditioning system with primary refrigerant

Researcher	Refrigerant	Nanoparticle	Lubricant	Nanoparticle mass fraction	Evaluation
Balaji et al. [43]	R-22	Al2O3	Binary mixture of water and Ethyl glycol (EG)	0.25-0.75 Vol. %	Results indicates that COP was increased by around 31% for 30:70 Ethyle Glycol :Water with a flow rate of 2LPM, and an increment of 49.32% for the nanofluid with 0.75% nanoparticle volume concentration with a flow rate of 2 LPM. Power consumption was reduced by 12.24%
Firouzfar et al.[44]	methanol	Silver	methanol	0.01% wt%	The experimental results demonstrated that the rates of energy saving for cooling and reheating was increase by 8.8-31.5% and 18-100% respectively if methanol-silver nanofluid was used in the same THE without changing the other parameters.
Husainy et al. [46]	R134a	CuO	Polyester oil	0.25-1% wt%	The study demonstrated that in comparison to a traditional system, the compressor work was reduced by 21.37 %, while real COP, theoretical COP, and carnot COP were increased by 26.92 %, 4.45 %, and 7.6 %, respectively
Altohamy et al.[48]	R-404A	Al2O3	Water	0.5-1% Vol%	The results show that there is the percentage of reduction in complete charging time at HTF inlet temperature -12oC attained approximately 32%, 28%, 18%, 12% at HTF volume flow rate of 12, 10, 8, 6 lpm respectively.
Rahman et al.[56]	R-407c	Single wall carbon nanotube (SWCNT)	R-407c	5% Vol %	Results showed that the cooling load was reduced by 31.5 percent, and the introduction of nanoparticles reduced the compressor's consumption work input by roughly 202.56 W,

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					resulting in a 5 percent boost in total system performance.
F. Ahmed & Khan [49]	R134a	Cu and Al2O3	Water	1-5% Vol %	Results indicated that COP increased by 22.1 % for a volume fraction of 5% Al2O3 nanofluid and by 29.4% for copper nanofluid.
Hussen [51]	R22	TiO2	Mineral oil	0.01% Vol.%	Results showed that the average compressor effort was reduced by 13.3%, resulting in an increase of 11.99 percent in the COP.
Colangelo et al.[53]		Al2O3	water-glycol		Results showed that the use of a nanofluid based on a water-glycol mixture and alumina improves efficiency by around 10% while lowering the HVAC system's electrical energy usage.

approximately 8.0 – 11.1 % greater than that of no nanofluid chilled water. Abdel Hady et al.[59] investigated the thermal performance of a chilled water air conditioning unit with different concentrations of alumina nano fluids (0.1, 0.2, 0.3, 0.6, and 1% by weight) and pure water. The experiments were carried out by varying the flow rate of the working fluids (alumina nano fluids and pure water) from 2, 3, and 5 Lit/min, as well as the flow rate of the incoming cooled air from 80, 150, and 250 CFM. When comparing nanofluids (Al2O3-water) to pure water, the experimental results show that it takes less time to achieve the desired chilled fluid temperature for all concentrations of nanofluids (Al2O3-water). Furthermore, the results revealed an increase in the COP of about 5% and 17% for alumina nanoparticle concentrations of 0.1 and 1% by weight, respectively. Nam & Zhai[60] analysed the air-side and water-side cooling capacity, as well as associated impact factors, of six representative active chilled beam systems in a full-scale laboratory. The study looked at the effects of supply airflow rate and cooling coil water supply temperature on the energy performance of active chilled beams in particular. The study also confirmed the effects of active chilled beam air supply nozzle diameters on cooling performance. The outcome showed that when the primary airflow rate rises or the water inlet temperature falls, the dominant water cooling capacity, which determines the total cooling capacity, rises. When the primary airflow rate or the water inlet temperature both rises, the air-side cooling capacity rises. With an increase in primary airflow rate and water inlet temperature, the air-to-water cooling capacity ratio rises. M. S. Ahmed & Elsaid [61] tested the performance of a chilled water air conditioning system (CWACS) using hybrid nanofluids containing different types of nanoparticles such as Al2O3 and TiO2, as well as pure water as a secondary working medium base fluid. The results showed that a single Al2O3/H2O nanofluid contributed a greater coefficient of performance and a shorter elapsed time for chilling a chiller system's fluid. In compared to TiO2/H2O, Al2O3/H2O provided lower compression ratio and higher refrigeration effect values by roughly 4.1% and 5.3%, respectively. Purohit et al.[62] compared the performance of an alumina nanofluid (with 0.5 %, 1.5%, and 2.5% particle volume fraction) cooled double pipe gas cooler to that of a water cooled gas cooler in a trans-critical CO2 refrigeration cycle. Their research shows that for the same Reynolds number, the performance of an alumina nanofluid cooled system outperforms a water cooled system.

Liu et al.[63] studied the effects of copper (Cu), copper oxide (CuO), and multi-walled carbon nanotube (MWNT) on the thermal conductivities of ethylene glycol, water, and synthetic engine oil, as well as the system performance of a 10-RT water chiller (air conditioner) subjected to MWNT/water nanofluid at the standard water chiller rating condition in the flow rate range of 60 to 140 L/min. At a flow rate of 100 L/min, the nanofluid system showed a 4.2 % improvement in cooling capacity and a slight decrease in power usage of roughly 0.8%.

The coefficient of performance of the water chiller was also found to be 5.15% higher than that of the water chiller without nanofluid. F. Ahmed [24] evaluated the effect of Al2O3 nanofluid as a secondary refrigerant in a refrigeration system at different volume concentrations (0.02-0.15%), mass flow rates (40-80 g/s), and nanofluid inlet temperatures (30-40oC) in an experimental setting. The results showed that at a mass flow rate of 80 g/s and a volume concentration of 0.15%, a maximum COP of 6.5 was attained for nanofluid inlet temperature of 40oC. Figure 3 shows the refrigeration system's coefficient of performance for mass flow rate of secondary loop water-Al2O3 nanofluid for various volume fractions at 400C inlet temperature.

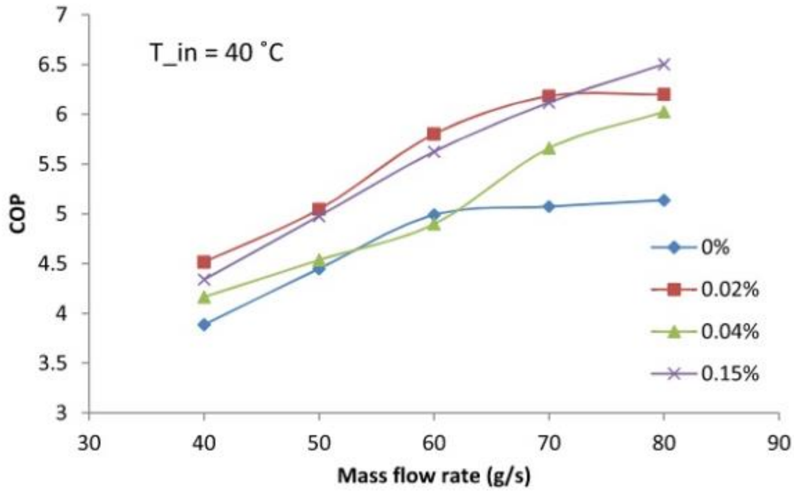

Figure 3. Coefficient of Performance Verses mass flow rate of secondary loop nanaofluid for Various volume fraction at inlet temperature [24]

Abbud et al.[64] conducted an experiment to improve the performance and efficiency of the chiller water system and the thermal conductivity by mixing a nano-fluid aluminium (Al) with ethylene glycol (EG) at various concentrations (0.02, 0.04, 0.06, 0.08, and 0.1 %). The results demonstrate that the volume fraction concentration of nanoaluminum (Al) with ethylene glycol (EG) grows as the coefficient of performance COP improves, and that adding nanoparticles to ethylene glycol (EG) produces a value enhancement of 29% when compared to ethylene glycol (EG). With an increase in the coefficient of performance, the temperature of the incoming nanofluid rises. Ahamed et al.[65]carried out research to compare the performance of a water cooler by replacing the compressor lubricating oil with Si3N4 nanoparticles and Si3N4 nanoadditives with TBAI surfactant at a concentration of 0.6% by volume. In comparison to the POE oil alone, the experimental findings showed that the COP of the water cooler was increased by 36.39% and 29.6% at 10lit load for nanolubricant and nanolubricant/surfactant, respectively. Anandakumar J [66] used a sonication procedure to assess the performance of a chiller employing Nano fluid and a water-cooled condenser with TiO2 Nano powder 100nm mixed in distilled water. The testing results reveal that when utilising Nano fluid instead of base fluid, the COP of the chiller unit increases, as does the flow rate and performance. Nair et al.[67] thoroughly investigated the thermal conductivity increase of R718 nanofluids based on CuO, Al2O3, and TiO2 nanoparticles using experimental values from the open literature. By analysing existing thermal conductivity data, a new model for forecasting the thermal conductivity enhancement ratio of R718-based nanofluids was presented, which was followed by regression analysis and experimental validation. When compared to other factors, it was discovered that the particle volume fraction had the most significant effect on the thermal conductivity enhancement of nanofluids.

Nanofluid application in heating system

Bobbo et al.[68] investigates their potential use of nanofluid as thermal fluids in heat pumps/Ground Source Heat Exchangers (GSHEs) in order to optimise complete systems for building and district heating and cooling applications throughout the EU's various subterranean and climate conditions. They investigate the use of four different concentrations of fumed Al2O3 nanoparticles in water as a secondary fluid in a heat pump-geothermal probe system, namely 3%, 5%, 30%, and 40%. The results showed that the fluid with the lowest concentration, 3wt%, appears to have some application potential, at least at temperatures above 40-50°C. It was also realized that the nanofluid would not likely be useful as a thermal vector in the ground loop, it might be utilised as a

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secondary fluid to transmit heat from the condenser to fan coils (inlet temperatures about 40-50°C) or radiators or air heaters (inlet temperatures around 60-70°C).

Experiments on copper oxide, aluminium oxide, and silicon dioxide nanofluids with 60:40 ethylene glycol and water solution (binary fluid) as a base fluid were carriedation out for the heat transfer enhancement by Kulkarni et al. [69], as well as calculations for typical finned-tube heat exchangers used as a heating system in cold-climate buildings. The study found that employing nanofluids in heat exchangers could lower volumetric and mass flow rates while also reducing pumping power. The findings also revealed that using nanofluids to heat buildings might lower the size of the heat transfer system, the associated pressure loss, and the subsequent pumping power, reducing pollution indirectly. Sednin et al.[70] simulated a vertical geothermal heat exchanger using a nano fluid (ethylene glycol-Al2O3) at different volumetric concentrations (2%-6%). The results reveal that for the determined optimal volume particle concentrations of nanofluid, the temperature differential between the nanofluid and the base fluid heating increases, resulting in improved heat exchanger performance. Tarodiya et al.[71] studied the performance of a ground heat exchanger (GHX) using six distinct water-based nanofluids (Al2O3, CuO, graphite, multiwalled carbon nanotube, graphene, and Cu).The study showed that with a temperature difference of 7°C to 15°C, graphite nanoparticles achieved the largest increase in output fluid temperature and reduction in pipe length of 68.3% and 63.3%, respectively. Figures 4A and 4B show how changes in flow rate affect the increase in fluid outlet temperature differential and the reduction in GHX length for various nanofluids. With graphite nanoparticles, a 65.2% decrease in outlet fluid temperature and a 42.3% reduction in pipe length were achieved, respectively, with a flow rate increase of 0.4 L/s. The effect of increasing GHX performance with nanofluid decreases as the circulating fluid flow rate increases and the temperature difference between the soil and the inlet fluid temperature decreases.

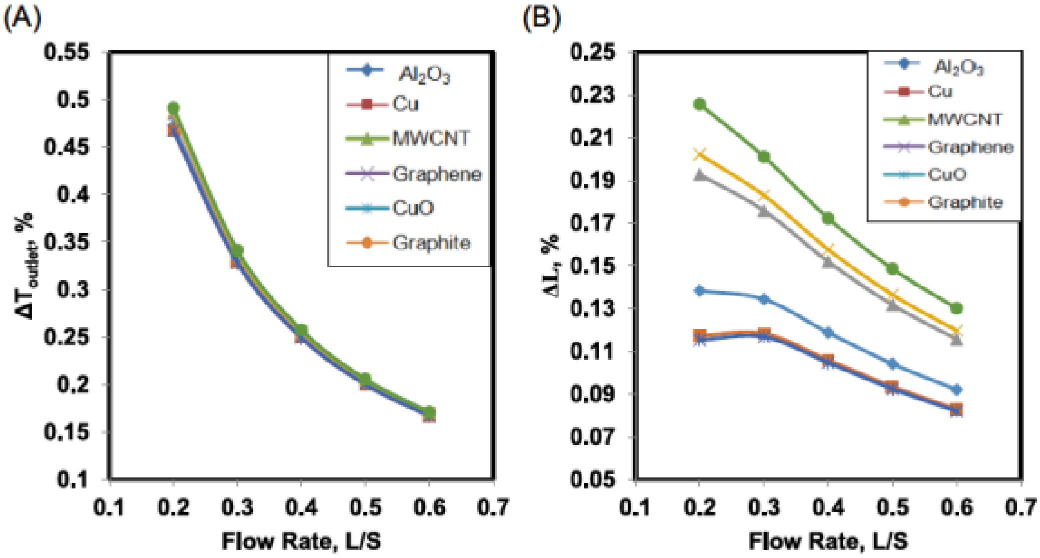

Fig. 4. Variation of (A) outlet fluid temperature difference and (B) reduction in GHX length. GHX, ground heat exchanger; MWCNT, multiwalled carbon nanotube [71]

Strandberg & Das [72] done the theoretical research into the use of copper oxide nanofluids in building hydronic heating systems to compare the convective heat transfer coefficient and pumping power requirements of copper oxide nanofluids with different particle volume concentrations. The results show that the CuO/60% EG nanofluid has higher heat transmission capabilities, which could contribute to building heating systems work better. The results reveal that for a nanofluid of equal concentration cycling at equal velocity, a larger convective heat transfer coefficient is produced at higher temperatures. With particle volume concentration, frictional pressure loss and pumping power rise relative to the base **Table 3. Research on the subject application of air conditioning system with secondary refrigerant**

Researcher	Refrigerant	Nanoparticle	Lubricant	Nanoparticle mass fraction	Evaluation

Mahdi et al.[57]	R-407c and R-134a	TiO2	Water	0.05-0.1% Vol.%	Results shows that the COP of a water chiller system using R-134a is 28% higher than that of R407c.
Sunu et al.[58]	R-22	Al2O3	Water	0.1% Vol.%	The studies shows that heat transfer increased as the mass flow rate of chilled water increases. At a given mass flow rate, nanofluid chilled water improves heat transfer by around 8.0 – 11.1 % to no nanofluid chilled water.
Abdel Hady et al.[59]	R-134a	Al2O3	Water	0.1–1 wt.%	The results shows that the addition of alumina nano particles to pure water improved the heat transfer characteristics of the working fluids (pure water). It has also been shown that increasing the concentrations of alumina nano particles reduces the elapsed time.
M. S. Ahmed & Elsaid [61]	R134a	Al2O3, TiO2, and a hybrid of Al2O3/TiO2	Water	0.05-1% wt%	Experimental results indicated that for chilling the fluid in a chiller system, a single nanofluid of Al2O3/H2O gave a greater coefficient of performance and a reduced elapsed time. In compared to TiO2/H2O, Al2O3/H2O provided lower compression ratio and higher refrigeration effect values by around 4.1% and 5.3%, respectively.
Purohit et al.[62]	CO2	Al2O3	Water	0.5-2.5 Vol.%	Results shows that the COP of the nanofluid cooled refrigeration system is higher only when the Re comparison criterion is equal, but the water cooled system dominates when the pumping power is equal.
Liu et al [63]	R-22	multi-walled carbon nanotube (MWNT)	Water	0.1-5 Vol.%	Results shows that at room temperature, the nanofluid's thermal conductivity increases by only 1.3%, but its cooling capacity increases by 4.2% at the standard rating condition. The addition of nanofluid to the standard rating condition can raise the COP by 5.15% compared to the standard rating condition without nanofluid.
F. Ahmed [24]		Al2O3	Water	0.2-0.15 Vol.%	The results showed that at a mass flow rate of 80 g/s and a volume

					concentration of 0.15%, a maximum COP of 6.5 was attained for nanofluid inlet temperature of 40oC.
Mahdi et al.[57]	R-407c and R-134a	TiO_2	Water	0.05-0.1% Vol.%	Results shows that the COP of a water chiller system using R-134a is 28% higher than that of R407c.

fluid, but decrease with mean fluid temperature. In fig. 5. the heat transfer coefficients for the base fluid and nanofluid up to 4% volumetric concentration are plotted against pumping power. At 360 K, the pumping power required to produce a particular heat transfer coefficient for nanofluids is typically 50% lower than that necessary for the base fluid. Strandberg & Das [73] was used a mathematical model to evaluate the performance of hydronic finned-tube heating units with nanofluids (comprised of either CuO or Al_2O_3 Nanoparticles) to that of a standard heat transfer fluid made up of 60% ethylene glycol and 40% water by mass (60 % EG). When compared to heating output with the base fluid, the model predicts an 11.6% increase in finned-tube heating output with the 4% Al_2O_3/60% EG nanofluid and an 8.7% increase with the 4% CuO/60% EG nanofluid under certain conditions.

The results shows that the finned tube with 4% Al_2O_3/60% EG has the lowest liquid pumping power of all the fluids modelled at a given heating output. Strandberg & Das [74] experimented with a hydronic air heating coil to assess its performance with a 1% Al_2O_3/60% EG nanofluid and compare heat transfer performance to that of a 60% EG coil. Under **Table 4. Research on the subject application of heating system**

Researcher	Nanoparticle	Base Fluid	Nanoparticle mass fraction	Evaluation
Bobbo et al.[68]	Al_2O_3	Water	3%,5%, 30 or 40 % wt%	Results shows that it could be used as a secondary fluid to transport heat from the condenser to fan coils (inlet temperatures of 40-50°C) or radiators or air heaters (inlet temperatures of 60-70°C) but in the ground loop, the nanofluid is unlikely to work as a thermal vector
Kulkarni et al.[69]	CuO, $Al_2O_3$and SiO_2	60:40 ethylene glycol and water solution (binary fluid)	2%-6% Vol%	Results shows that the use of nanofluids to heat buildings can minimise the size of the heat transfer system, as well as the pressure loss and pumping power associated with it. This will cut energy consumption from power plants and, as a result, indirectly reduce pollution.
Sednin et al.[70]	Al_2O_3	Ethylene glycol	2%-6% Vol%	The results reveal that when nanoparticles are added, the temperature differential between the nanofluid and the base fluid heating increases due to an increase in thermal conductivity.
Tarodiya et al.[71]	Al_2O_3, CuO, graphite, multiwalled	Water	12%-6% Vol%	The result shows that the effect of increasing GHX performance with nanofluid decreases as the circulating fluid flow rate increases

	carbon nanotube, graphene, and Cu			and the temperature difference between the soil and the inlet fluid temperature decreases. However, when pipe radius, borehole radius, and depth grow, it improves.
Strandberg & Das [72]	CuO or Al2O3	60:40 ethylene glycol and water solution (binary fluid)	1%-4% Vol%	The results shows that The heat transfer performance of the Al2O3/60 percent Ethylene Glycol and CuO/60 percent Ethylene Glycol nanofluids is superior to that of their respective base fluids, requiring less pumping power or smaller heating equipment to achieve the same amount of heat transfer.
Strandberg & Das [74]	Al2O3	60:40 ethylene glycol and water solution (binary fluid)	1% Vol%	The test results showed that the 1% Al2O3 nanofluid generates a quite higher rate of heat transfer than the 60% EG and the nanofluid achieved a rate of heat transfer that was 2% higher than the 60% EG at Re = 3000.
Bobbo et al.[68]	Al2O3	Water	3%,5%, 30 or 40 % wt%	Results shows that it could be used as a secondary fluid to transport heat from the condenser to fan coils (inlet temperatures of 40-50°C) or radiators or air heaters (inlet temperatures of 60-70°C) but in the ground loop, the nanofluid is unlikely to work as a thermal vector
Kulkarni et al.[69]	CuO, Al2O3 and SiO2	60:40 ethylene glycol and water solution (binary fluid)	2%-6% Vol%	Results shows that the use of nanofluids to heat buildings can minimise the size of the heat transfer system, as well as the pressure loss and pumping power associated with it. This will cut energy consumption from power plants and, as a result, indirectly reduce pollution.
Sednin et al.[70]	Al2O3	Ethylene glycol	2%-6% Vol%	The results reveal that when nanoparticles are added, the temperature differential between the nanofluid and the base fluid heating increases due to an increase in thermal conductivity.

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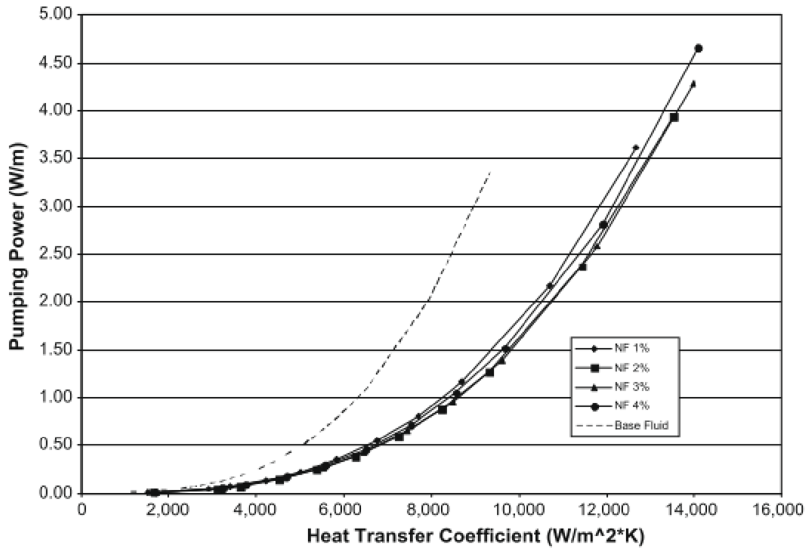

Fig. 5. Variation of pumping power per unit length of pipe with convective heat transfer coefficient, T = 360 K Temperature [72]

certain conditions, testing showed that the 1% Al2O3 nanofluid generates a quite higher rate of heat transfer than the 60% EG and the nanofluid achieved a rate of heat transfer that was 2% higher than the 60% EG at Re = 3000.

Conclusion

The major goal of this research was to provide an overview of recent developments in nanofluid application in HVAC. This paper summarises the majority of investigations on the use of nanofluids in refrigeration and air conditioning systems with primary and secondary refrigerant loops, as well as heating systems. Nanofluids are predicted to be used in a variety of heat transfer applications in the near future due to their improved heat transfer characteristics. The following observations can be drawn from the current review:

1. By employing nanofluid, the compressor's power usage as well as total energy consumption can be lowered.
2. Increasing the nanoparticle proportion can minimise the total charging time of the heat transfer fluid as well as the elapsed time.
3. Using nanofluid is said to improve freezing speed and coefficient of performance in cooling equipment.
4. Nanofluid can be used to transfer heat from the condenser to fan coils, radiators, or air heaters as a secondary fluid in heating system.
5. Nanofluids could lower volumetric and mass flow rates, as well as pumping power, in heat exchangers.
6. Indirectly decreasing pollution by using nanofluids as a heat transfer fluid in building heating applications minimises the size of the heat transfer system, the accompanying pressure loss, and the following pumping power.

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