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Global Solutions for Sustainable Heating, Ventilation, Air Conditioning, and Refrigeration Systems and Their Suitability to the New Zealand Market

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Abstract: This paper attempts to find alternative ways in which heating, ventilation, air conditioning and refrigeration systems can be made more energy efficient and sustainable at a global level. Eight technologies or solutions that either passively or supplementarily reduce the heating or cooling load required by a structure are detailed. These technologies or solutions were then presented to heating, ventilation, air conditioning and refrigeration industry professionals in New Zealand to determine their viability and further establish market readiness towards integrating new, innovative, and sustainable solutions in New Zealand. A literature review was conducted to establish the performance of the selected solutions and understand their operational principles and the efficiency they provided. Qualitative research and data collected via semi-structured interviews provided the data for assessing the viability of the selected technologies in the New Zealand market. Following a thematic and hybrid-thematic analysis of the data, the technologies were ranked, and suggestions were made to help improve innovation and energy efficiency in the heating, ventilation, air conditioning, and refrigeration industry in New Zealand. Of the technologies selected, airtightness, heat recovery ventilation retrofits, materials and design principles, and photovoltaic hot water heating were identified as the most viable. The New Zealand market was deemed not to be in a good position to adopt new or alternative solutions. The main issues affecting New Zealand's market readiness to assimilate innovative and energy-efficient solutions are a lack of new technologies, poor standards of education throughout the industry, a lack of regulation, and a lack of government incentives.

Keywords: heating; ventilation; air conditioning; HVAC; New Zealand; energy; efficiency; sustainability; innovation

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1. Introduction

The World Bank predicts that nearly 70% of the global population will live in cities by 2050 [1]; in New Zealand, this is already at 87% [2]. The energy demand from New Zealand's residential sector accounts for 33.8% of total demand. If commercial usage is included, that number increases to 57.9%. Residential energy usage related to the heating, ventilation, air conditioning, and refrigeration (HVAC&R) trade in New Zealand is 74%, or 25% of the country's total production [3].

With more people living and working indoors, and with the temperature and weather associated with global warming, the need for indoor environment control for either the inhabitation or the storage of goods is expected to increase. There are two potential solutions to this problem: either produce cheaper, more accessible systems that increase energy demand, or explore integrated solutions that reduce the heating and cooling demand of our buildings, so they use less energy and are more efficient. This research details eight technologies that fit into the categories of geothermal, building envelope, design, and alternative energy sources and assesses them for viability in the New Zealand market.

Interior temperature control in buildings already accounts for 32% to 40% [4] of the total international electrical energy generation. With significant populations around the world and large minority groups rising out of poverty, the option for indoor climate control will become attainable. An expected increase in demand for heating or cooling leads to either uncomfortable living conditions or power/energy poverty in low socio-economic communities [5]. When combined with expected temperature increases associated with global warming, the requirement for electrical energy to power these systems will dramatically increase.

With the expected increase in demand for indoor temperature control, mass-producing cheap HVAC&R systems will significantly increase the electricity demand of buildings. An alternative approach exists to reduce the energy demand of traditional systems or supplement their performance with passive solutions to improve efficiency. The integration of passive design and the availability of more efficient technologies will reduce energy demand and improve access to better quality, more economical, and healthier systems for lower-income families in emerging markets.

It is plausible that the motivation that drives the customer's decision to choose a product based on the principles of its sustainability or efficiency is not definitive. The industry should strive for efficiency and provide healthy, affordable, and comfortable environments for the people who occupy and inhabit the spaces we build.

This work aims to find alternative ways for HVAC&R systems to be made more energy efficient and sustainable at a global level, and, further, to establish market readiness towards integrating new, innovative, and sustainable solutions in New Zealand.

There is a need to understand the challenges the New Zealand HVAC&R market faces when implementing innovation, identify any underlying barriers that restrict improving the efficiency of the systems, and uncover attitudes towards new or alternate techniques or technologies.

2. Background

A joint agreement is that building energy requirements make up a significant portion of global energy consumption. Although there is no exact number agreed upon across the literature reviewed, the consensus is that it is a considerable proportion, likely between 20% and 50% globally; 22% of the residential sector in the United States of America [6], 50% of global energy usage worldwide [7], and 20.1% of the total delivered energy worldwide [8]. This demand is likely to increase in the future with a global move towards a high-density, urban population whose inhabitants' time is spent primarily indoors [9]. The literature shows that refrigeration and air conditioning (excluding heating and ventilation) are responsible for about 15% of the total electricity consumption around the world [10].

New Zealand's climate, as described by the Köppen–Geiger climate classification system, is temperate, with no dry season, warm summer (Cfb) [11]. Whereas other climate types exist, Cfb is predominant and describes all areas of high-density population. This work focuses on identifying HVAC&R systems that are implementable in New Zealand's climate. As such, the coefficient of performance (COP), a common thermodynamic methodological measure that represents the efficiency of a system, is used to compare the systems' useful heating or cooling produced (Q) to the work required (W). This comparison is conducted based on a widely accepted framework to engineer passive cooling systems consisting of three steps: prevention of heat gains, modulation of heat gains, and heat dissipation [10].

This process was used as a starting point to identify possible solutions. The identified solutions are discussed under the following categories:

(1) Geothermal solution,
(2) Envelope and Building Design solution, and
(3) Alternative energy sources.

2.1. Geothermal Solution

The geothermal principle is a renewable energy application. Outside air temperatures fluctuate with the yearly seasonal cycle; however, the temperature of the soil below the surface remains relatively constant. Caused by the Earth's temperature, this temperature stays at a constant just below the outside air mean temperature [10].

Geothermal heating and cooling uses the subterranean soil as an energy transfer medium. At a depth of up to 10 m below ground level, soil temperatures are affected by the daily and seasonal weather cycles; below 10 m depth, temperatures become relatively constant, followed by a minor increase in temperature with depth at a rate of 2.5 °C/100 m [12].

Soil recharge is a drawback of all geothermal applications. As heat is transferred or absorbed by a heat exchanger, the temperature of the soil changes, and the differential between the soil temperature and the outdoor air temperature reduces, reducing the potential of the system. A recharge period is required in all geothermal applications to allow the soil temperature to return to its natural value.

2.1.1. Geothermal Heat Pump (GEP), Ground Source Heat Pump (GSHP)

A Geothermal Heat Pump (GHP), also known as a Ground Source Heat Pump (GSHP), can be either installed horizontally (in shallow trenches 1 to 2 m deep) or vertically down boreholes up to 250 m in depth. Heat is extracted or rejected to the ground by means of buried pipes, through which a heat transfer fluid usually circulates, either water or a water/antifreeze solution [13]. Despite having higher installation costs, vertical installations are more common.

GHP/GSHP limitations to implementation can be described as non-standardised system designs, significant capital cost compared to other systems, limited skilled individuals knowledgeable in the installation process, and government policy limitations [14]. Upfront capital cost for installation and groundwork is a disadvantage of the Geothermal Heat Pump solution [14].

2.1.2. Foundation/Slab Heat Exchanger (FHX), Geothermal Heat Exchanger Pile (GEP)

Geothermal Energy Piles (GEP) are systems that are not exposed to the groundwork cost associated with Geothermal Heat Pumps. This is because the technique mitigates the requirement for additional excavation and groundwork by utilising the excavation or pile boring process during construction. The heat exchanger components (absorber pipes) are installed in the excavation voids before the pile/foundation material is poured; this transforms the pile into a heat exchanger. Reinforced concrete piles have been found to be advantageous in thermal energy transfer due to the material's high thermal storage capacity and enhanced heat transfer capabilities [15].

The system can be used for both heating and cooling demands with the seasonal cycle. In warmer seasons, when occupants require cooling, the system will use the reinforced concrete pile and soil material as a heat sink. In the colder seasons, this energy is recovered from the ground, which is used as a heat source for the building [16]. GEPs cannot completely offset the energy usage, and electrical energy input will still be required to drive a heat pump [17].

A Foundation Heat Exchanger (FHX) is a concept for a Horizontal Ground Heat Exchanger (HGHX) and latent heat thermal energy storage (LHTES) system [18]. An FHX system uses absorber pipes embedded in the foundation (rather than piles) during the construction phase. FHX installations have properties like GEPs, and such will be considered a similar concept/technology.

GEPs and FHXs do not have the excavation costs of GHXs and are shown to be economically beneficial with time; they, too, experience low maintenance costs as most of the material is embedded in concrete. As it is a new technology, there will be a lack of experienced professionals with experience in these installs; universal guidelines are not fully developed and will likely be required to ensure consistency. GEPs with closed-loop systems offer a COP of between 3.0 and 5.0 [16].

2.1.3. Earth Air Heat Exchanger (EAHE)/Earth Air Tube Heat Exchanger (EATHE)

A building structure can either be in direct or indirect ground communication [19]. Direct ground communication occurs when the building envelope directly interacts with the earth, either partially or fully embedded, for example, in subterranean or underground basements. Indirect communication occurs with systems such as Earth, Air Tunnel Heat Exchangers (EATHE), Earth Air Heat Exchangers (EAHE), or Geothermal Heat Pumps, where heat is transferred through a medium to the building. In the examples of EATHE and EAHE, the air is passed through pipes buried underground, the temperature of the soil is transferred to the air via the pipe walls, and the air is then passed into a structure that is not completely embedded in the terrain.

Ahmed et al. [20] identify two different categories of EAHE, closed loop and open loop. The closed-loop system does not exchange the air in the system with the outdoor air. The air inside the room is cycled through the EAHE and back into the room, heating or cooling depending on the temperature difference between the soil and air. In the open-loop system, fresh air is passed through the EAHE before being distributed to the room and later vented to the atmosphere via an outlet. Where there is the benefit of improved air quality for the open system, the closed loop is considered more energy efficient as the continual cycling reduces the size of the required exchanger tube.

Reported performance of Earth Air Heat Exchanger systems is varied. Literature shows the system's performance in dry climates where the technology originates, where the system was able to reduce incoming air temperature from a mean of 30.9 °C by 7.5 °C; however, as the heat was transferred to the soil, the effectiveness reduced [21]. These types of applications may be viable in the summer hot, dry regions of New Zealand, such as Canterbury or Hawkes Bay.

2.2. Envelope and Building Design Solution

The literature for locations under the Köppen–Geiger climate classification temperate (Cfb) states that interior thermal performance and comfort for occupation should begin with an airtight envelope, supplemented with energy-efficient passive heat sources [22].

A combination of a Trombe wall, shading, ventilation, and insulation is the most effective and low-cost passive option for this climate type [9]. Many literature sources agree with the requirement for insulation and suggest reducing the building envelope's exposure to the outside environment [8,23,24]. The following categories, namely, Trombe wall, roof insulation, materials, reflective surfaces, insulation, and phase change materials, will be considered together as envelope and building design principles.

2.2.1. Trombe Wall

A Trombe wall is an indirect gain passive solar system; its purpose is to supply heating and ventilation in buildings by means of solar radiation [25]. Typical construction of this feature consists of a thick slab wall with a heat-absorbing material exposed to a solar source. A transparent glazing, typically glass, is placed with an air gap 2–10 cm away from the wall [26].

Literature is inconclusive regarding the optimal thickness of the slab wall; however, 30 to 40 cm is around the commonly stated dimension [27], 15 cm is very sensitive to changes in solar radiation, while 30 cm thickness was enough to dampen these changes to an acceptable degree for occupation. While a thickness of 30 to 40 cm is recommended [26,28], and 35 cm is the mean [29], 45 cm (thickness) should be used when energy is desired to store energy for nocturnal warming [29]; however, if warming during the day is the priority, a thickness of 20 cm is the best choice. Ideal materials for construction vary, with solid brick having the highest cumulative heat gains in summer and lowest in winter [29], whereas others recommend a concrete-constructed wall [26,28]. A common agreement for the performance of the system is highly dependent on design details, such as size, glazing type, absorber, air layer thickness/channel width, and vents [29]. Divergence from an effective 201 design would limit peak efficiency and energy reductions.

Literature shows that the application of a Trombe wall in Ancona, Italy (climate classification Cfb) contributed to a reduction of heating demand of around 28% [29]. Furthermore, recommending tailored shading devices and vents with daytime operating schedules and a night ventilation strategy for similar regional locations can result in a reduction of cooling loads by 35% or more. All materials and techniques described in the literature would be accessible and implementable in the New Zealand market.

2.2.2. Roof Insulation

In the United States, 14% of total heat gain for single-story residential buildings comes from the roof structure; this figure is lower for multi-story structures [30]. Literature shows research conducted on the possibility of heating and cooling with air recovered from the roof space in typical existing New Zealand residential buildings, and recommends that roof space air should not be used for this purpose, as the benefits were not significant [31]. It was found that a lack of airtightness, lack of insulation, and high thermal conductivity of materials typically used in New Zealand result in significant reductions in the temperature of the roof space when incident solar radiation is no longer available, be it seasonal, meteorological or diurnal [31].

Another research study explored different roof configurations and material performance under tropical conditions and found that the temperature of common flat roofs is 10 °C above the ambient temperature, rising to 15 °C on hot days [30]. They compared the thermal performance of different materials and found that clay tile-clad roofs had better performance over steel roofing, with the latter having an additional maximum ceiling temperature rise of 6 °C along with higher daily fluctuations. When comparing roof configurations, flat roofs, compared to roofs of different geometries, changing to a gabled or hip roof design results in a reduction of temperature by up to 5 °C [30].

By using better available cladding materials, ensuring airtightness, and using favourable roof configurations, the stability of roof space temperature can be controlled. This minimises the losses of energy to and from the building through the roof space, stabilising the internal temperature and resulting in less energy requirement to meet a comfortable standard.

2.2.3. Materials, Reflective Surfaces and Insulation

It is widely accepted that to conserve energy, the thermal performance of buildings needs to be upgraded [32]. Additionally, modern homes are easy to heat and difficult to cool. Several studies have shown the potential of using cheaply attainable materials to control the amount of energy transmitted into and attained by a building envelope. By comparing several building materials (hollow block, red, brick, and solid block) treated with different layers of plaster, insulation material, and reflective coatings, and found that the treatment of two layers of plaster insulation and a reflective surface showed a reduction of thermal load by up to near 49% to a non-treated configuration [7]. When compared to plaster and painting against exterior shade and natural ventilation, the combination of the latter was found to be more effective as a cooling technique [33].

A standard agreement is the unavailability of inferior environmental conditioning for low socioeconomic households. Where this occurs in hot, dry, and equatorial climates, natural ventilation should be implemented to reduce the energy demand required by active environmental controls [5,7,24,34]. Furthermore, natural ventilation [5], as a means for controlling thermal comfort in low socio-economic households under hot conditions, only caused large periods of thermal discomfort, so a mixed mode solution of air-conditioning during the middle of the day, with natural ventilation, was required during dawn and evening. For these climates, the agreement is made for the benefit of reflection, shading, and insulation as an affordable method for reducing energy consumption [7–9,21,24,32,34].

2.2.4. Phase Change Materials

Phase Change Materials (PCM) are a Latent Heat Thermal Energy Storage (LHTES) technology. PCMs work by either storing or releasing latent heat during a phase change process within the material. With this application, PCMs make fantastic insulation materials that reduce heat loss in winter and slow heat gain in summer.

Considerable energy performance can be gained by incorporating PCMs into building envelopes, such as walls, floors, and roofs; however, several factors affect the performance that can be achieved by considering the seasonal effects on temperature, climate, orientation, thickness, phase-change temperature and position of the PCM placement [35]. By retrofitting building envelopes with LHTES, building energy consumption can be reduced by 20 to 50% [36].

PCMs as insulation material are recommended to be used as a supplement to traditional methods, not to replace them. Newer PCM products are easy to install, nontoxic, and can be produced from organic matter. As they are considered new technology that has not been fully adopted by the market, they are still considered expensive. PCM materials work best in temperate climates, where there is a significant difference between outside air temperatures during a diurnal cycle, for recharging purposes. For this same reason, they should not be recommended to tropical coastal installations where the temperature fluctuation is low. Phase Change Materials in Trombe wall designs have been proven to better store energy than conventional materials [37].

2.2.5. Airtightness, Solar, Heat Recovery Ventilation Retrofits

Solar heating, via direct methods (Trombe wall, equatorial facing facades) or transfer medium (Solar/Photovoltaic water heat exchanger), integrated with a Heat Recovery Ventilation (HRV) system, is a current and recurring methodology that exists globally for the climate type Cfb [22]. These methods reflect the theories of the Zero Energy Building (ZEB) methodology [8].

Heat Recovery Ventilation (HRV) or air-to-air energy recovery systems are defined as a device that is able to remove, extract, recover, or salvage heat from one airstream and transfer it to another airstream using a mechanical approach [38]. These provide energy efficiency by reducing the energy consumption required by either preheating or cooling air coming in from outside by transferring or absorbing thermal energy from the exhaust airstream. This effectively minimises the heating or cooling load required by a supplementary traditional air conditioning system. Based on climatic conditions, energy savings in the range of 20 to 35% for annual energy consumption can be achieved by employing air-to-air energy recovery systems [39].

However, heat recovery ventilation systems are not always efficient compared to standard ventilation systems, especially in low-energy buildings with a primary energy consumption of about 50 kWh/m^2 per year [40].

Retrofitting can be difficult due to the requirement for installing ducts and vents in the post-design phase or construction stage. This can be a compromise that risks lowering the efficiency of the system. While the plant can be designed well, the installation requires adequate design for the particular building, as well as proper installation and commissioning [41]. Without it, the system's benefits will be degraded.

2.2.6. Thermal Buoyancy Principles

○ Solar Chimneys.

This passive ventilation system operates by a density gradient that stimulates thermal buoyancy. By using the natural convection of air to ventilate a building, solar chimneys normally consist of a vertical shaft (chimney) vented at the top and open at the bottom. An external source heats the shaft, typically solar radiation. Through conduction, the air molecules' temperature increases and begins to rise, creating an updraft. The updraft lowers the pressure at the base of the chimney; this, in turn, draws in air from the interior of the building. The reduced pressure of the air inside the room then stimulates natural ventilation in the form of fresh air being drawn in from the outside.

Solar chimneys are a form of solar-induced ventilation that supplies natural ventilation to a building [42,43]. The feature has the benefit of lowering the indoor temperature of the building, improving the ventilation airflow rate, and improving the fire rating of the building through smoke ventilation.

Solar chimneys need to be designed properly to be effective. Tall, narrow structures are best suited; however, adverse flow reversal effects can occur if the ratio of the height to the diameter is less than 16 [44,45]. Research on the effects of the design of the roof structure on the performance of a solar chimney shows that buildings with solar chimneys and sloping roofs induced better ventilation rates over buildings with solar chimneys with flat roofs [44]. The best performance was attained when the roof structure sloped upward toward the chimney from all sides because of Bernoulli's principle.

These structures can be utilised for energy generation with the installation of turbines in the shaft [46], but this application is moving away from the scope of reducing the energy required by traditional HVAC&R systems.

Solar chimneys are suitable for hot and arid climates [44], so they may be implementable for summer conditions on the east coast of the North and South Islands of New Zealand [47]. Other applications are possible when coupled with an evaporative cooling system; the thermal buoyancy induced by a solar chimney, drawing air past an evaporative cooler, was able to reduce the peak cooling load of the evaporative cooling system in an office in Japan by 10% [10].

○ Domed Ceilings with Cupolas.

In the United States of America (and, to an extent, New Zealand), roof design is selected based on cost and aesthetic aspects [48]. This overlooking of the thermal performance of roof configuration leads to thermal discomfort and the use of fans and air conditioning systems as a corrective activity.

Solar energy collected by any roof configuration causes an increase in roof temperature. The characteristic of a domed roof or vaulted roof is the auto-shading effect. With the daytime passage of the sun, one side of the roof structure will be subject to direct sunlight whilst the other remains in the shade (with the sole exception of midday). This difference in transmission results in a warmer and cooler surface transmitting to the interior. This surface temperature differential promotes internal air movement as the warming of one side of the structure causes the internal air in contact with the surface to rise, with the opposite happening on the opposing side, where the cooler surface causes the air to subside. The hemispherical exterior shape of the structure has a unique effect via Bernoulli's principle: as air moves over the external surface, it accelerates over the crest, creating an area of low pressure. If a cupola or vent is placed at the peak of the dome, the negative pressure caused by air movement will cause suction and promote natural ventilation and extraction for the internal space. Under normal circumstances, this vent will expel warm air, thus lowering the interior temperature.

The literature provides ample information about the performance of the domed roof solution when compared to flat roofs. Further literature shows that domed/vaulted roofs provide lower internal temperatures than flat-roofed air-conditioned buildings in hot dry climates [49,50]. Solar energy absorption levels are undecided as Gómez-Muñoz et al. [51] found that hemispherical vaulted roofs received approximately 35% less solar energy than a flat roofs; however, this is inconsistent with the findings of Sedighi et al. [52] who found that heat transmitted through a domed roof is 70% more than a flat roof configuration for the same base area. Further, multiple domes did not show heat transfer improvement over flat roofs; however, heat transferability can be improved if cupolas are integrated into the design.

This design principle would be best suited to areas of New Zealand where there are high sunlight hours, as the system is designed around solar incidence and the requirement for ventilation and cooling.

2.3. Alternate Energy Sources

2.3.1. Integrated Solar/Photovoltaic Thermal (PV/T) and Hot Water Heating

Due to continuous efforts to reduce the heating demand of buildings, the percentage of energy used for hot water supply is predicted to increase decisively during the upcoming years [53], with the relative weight of energy consumption for domestic hot water having already notably increased [54].

Photovoltaic panels for electricity generation are a solution that supplements a building's energy requirements and can be used to provide energy for hot water heating. When comparing a photovoltaic loop heat pipe/solar-assisted heat pump (PV-LHT) water heating system to an air-source heat pump, it was shown that the lifecycle costs of the new system could be reduced by almost 30% over a standard air-source heat pump [55].

As for photoelectric efficiency, the highest value appears in winter [8,55], which is due to the effect temperature has on the efficiency of PV panels. It is well known that electrical efficiency in PC systems is reduced with increases in panel temperature [56]. As the temperature of the panel increases, the efficiency of electricity production decreases. This becomes problematic when peak electricity generation is typically available in summer months when hot water demand is generally at its lowest; the opposite is the case for winter, where generation is lowest and demand is highest, resulting in electrical generation being insufficient to meet the required heating load.

Photovoltaic Thermal (PV/T) is a solution that uses either air or liquid, acting as a cooling medium for the PV panel. Heat is transferred away from the back of the panel, increasing the panel's efficiency, and the heated air or liquid is then either moved into the home or elsewhere where it may be needed. A reverse cycle is possible where air or liquid can be cooled during the night. Relatively high initial investment costs and low overall efficiency of photovoltaic panels limit their viability [56].

2.3.2. Wastewater Source Heat Pump (WWSHP) and Heat Exchangers (WWHX)

As mentioned above, the relative weight of energy consumption for domestic hot water is expected to increase notably. Wastewater Source Heat Pumps (WWSHP) and Wastewater Heat Exchangers (WWHX) work by using the thermal energy that is stored in grey water and reducing it through heat exchangers. Heating is the primary cycle; however, cooling can be achieved in a reverse cycle, with heat being rejected into the wastewater stream.

There are two distinct applications: local systems, which exchange energy as the greywater leaves a premises, and district systems, where an exchanger integrated into the wastewater infrastructure benefits multiple buildings within its locality. Local systems are regularly used for hot water heating, achieved by recovering the thermal energy stored in water as it leaves the building and transferring it to cold water that acts as a heat transfer medium; this is cycled into the facets to increase the temperature of the water before reheating, this solution has been proven to reach energy savings between 30 to 50% in energy required to heat water for a shower [54].

Whereas local systems provide energy savings, which should not be ignored, district systems that recover heat from the sewer system are more relevant to the scope of the research. The constant flow and availability of wastewater, especially in urban and metropolitan areas, have led to its being deemed a reliable and renewable energy source. Heat recovery from sewer systems occurs in one of three ways: (1) sewer-integrated heat exchangers placed directly into the sewer system, (2) sieved wastewater, where particulates are removed to the water being passed through the heat exchanger, and (3) collection shafts, where the sewerage is stored in a collection chamber while energy is recovered, then returned to the main line [57,58]. The temperature of the sewer content is shallow in daily fluctuation [59]; however, it yearly fluctuates in a wider range, between 10 °C and 20 °C, with the lower being aligned with the warmer seasons and the higher with colder seasons [60]. This fluctuation aligns with the thermal demand from occupants of a building. Estimates show that over 500 district-level WWSHPs operate worldwide [53]. The feasibility of the district WWSHP depends on (a) the distance of the district to the WWSHP, with the shorter being beneficial, and (b) the volatility of the cost of electricity as a fuel for alternative heating applications [59]. District heating is expected to become more favourable as the cost of energy is generally expected to increase in the future.

The literature highlights the efficiency of the system with a COP range of 4.0 to 4.6 [53], when a constant flow rate of 5 L/s of sewerage is provided, a WWSHP can provide heating to an office building with a heating load of 60 W/m^2 [61]; this flow rate is considered replicable in urban areas. The efficiency of the system in economic terms is providing heating at €0.12 per kilowatt/hour (kWh) [57].

Issues experienced when implementing the system around the world include regulation modifications that were required to modernise and regularise wastewater laws to encourage private sector investment in Japan and China [61].

3. Method

The type of research conducted was qualitative. It began with a background study that utilised secondary research techniques and concluded with qualitative data collected through purposive sampling supplemented by snowball sampling.

The first stage of the research was to conduct research focusing on secondary research methods, such as online research, literature research, reviews, and case studies. Secondary research is a process that uses data that already exist [62]. Expanding on an in-depth literature review, the exploratory research was conducted using a systematic process of investigation. This investigative process analysed existing data to determine a solution's suitability to be assessed further by assessing its viability in the New Zealand Market.

3.1. Sampling and Interviews

Data were collected through semi-structured expert interviews. A purposive sampling method was implemented. This selection method was used as the expert opinion was deemed to be essential to attaining data that would accurately answer the research questions. As of January 2025, approximately 247 HVAC&R contractors are operating in New Zealand, with the majority being small, single-owned businesses [63]. A sample of eleven participants was selected for the study. While the sample size may appear small, expert interviews are a recognised qualitative method where depth of insight is prioritised over quantity. According to Gill et al. [64], data saturation in expert interviews is often achieved with fewer participants when the group is homogenous and highly knowledgeable. Hennink and Kaiser [65] noted that 9–17 interviews or 4–8 focus group discussions reached saturation in empirical studies.

The participants were selected based on two different group criteria. Group A participants were the initial participant set and consisted of professionals who met a minimum experience threshold. The experience requirement was fifteen years of construction industry experience, of which ten years' experience is required to be relevant to the HVAC&R trade. Group B participants were the secondary sample set and were selected based on recommendations from participants in Group A. Group B participants did not meet the minimum experience requirements of Group A participants; however, they were deemed competent by way of a professional association. Participants from both Group A and Group B were required to have New Zealand industry employment experience. Participant demographics are described in Table 1. The geodemographic information of participants is from Auckland, New Zealand (9) and Christchurch, New Zealand (2). All participants gave their time voluntarily.

Table 1. Participant Title and Group Composition.

Qualification/Position	Number of Participants	Group A/B
Engineer/Designer	4	3/1
Company Directors	2	2/0
Business Development Manager	1	1/0
Sustainability Manager	1	0/1
Market Manager	1	0/1
Project Manager	1	1/0
Quantity Surveyor	1	1/0

Participants were asked the following peer-reviewed questions to collect data that would be used to address the research questions:

(1) What is the current state of HVAC&R integrated solutions in New Zealand? Is New Zealand a leader or a follower on the global stage?

(2) The following technologies have been identified and are used in other regions of the world. Based on your experience, please rank from most viable to least viable in New Zealand. Please elaborate on any strengths or weaknesses of these identified technologies and any factors that may affect this ranking:

- Geothermal Heat Pump (GHP), Ground Source Heat Pump (GSHP).
- Foundation/Slab Heat Exchanger (FHX), Geothermal Energy Pile (GEP).

- Earth–Air Heat Exchanger (EAHE)/Earth–Air Tunnel Heat Exchangers (EATHE).
- Material and Design (Trombe Wall/Roof Insulation/Materials/Reflective Surfaces/Insulation and Phase Change Materials).
- Airtightness, Solar, and Heat Recovery Ventilation retrofits.
- Thermal buoyancy principles (Solar Chimneys, Domed Ceilings with Cupolas, etc.).
- Photovoltaic Thermal (PV/T), Hot Water Heating.
- Wastewater Heat Recovery (WWSHP), Wastewater Heat Exchangers (WWHX).

(3) Are there any key requirements, legislation, technologies, or infrastructure that New Zealand lacks that would support improving HVAC&R system efficiency?

(4) Please give me your opinion on New Zealand's readiness to assimilate new technologies.

When all questions had been answered, the participants were given the opportunity to raise or discuss any subjects, points of view, or issues that they personally felt were of concern to the industry that had not been expressly identified or covered, which would benefit the themes of the research project.

These questions were revised and refined, and ethics approval was granted on 20 June 2024, Ethics Notification Number 4000029195 for the collection of required data.

3.2. Analysis

An inductive thematic analysis was conducted on interview questions 1, 3, and 4, while an inductive/deductive hybrid thematic analysis was applied to question 2. NVivo was used as a coding mechanism, and Microsoft Excel was the software used to analyse the data. Data were manually coded, and themes were identified by the process outlined [66]. In qualitative research, few guidelines exist to justify an adequate sample size [63]. Common practice is to justify the sample size when the principle of data saturation has been reached. This occurs when no new information is obtained from interviews and/or observations. Saturation was met with a sample size of eleven.

4. Results

The results are detailed as the themes that were developed from the inductive thematic analysis of the data retrieved from the interview process. A short description detailing the common ideas that emerged from each theme has been presented below under the title of each interview question. Where an inductive/deductive hybrid thematic has been completed on interview question two, the data have been made available in Table 2.

- Interview Question One: What is the Current state of HVAC&R integrated solutions in New Zealand? Is New Zealand a leader or a follower on the global stage?

○ Leader or a Follower?

Most participants agreed that, due to New Zealand's relatively small population and market, the New Zealand HVAC&R industry is forced to be a follower on the global stage. Innovation in HVAC&R predominantly originates from the European market. Regulations tend to follow Australia's direction, and materials manufacturing is predominantly sourced from Asia. The geographical relationship of Australia also influences the New Zealand market by affecting the product lines that are made available to the market by the most prominent manufacturers.

○ The state of the HVAC&R industry in New Zealand.

Participants described the current state of the industry as neutral, neither good nor bad. More than half (6) of participants had a neutral opinion on the situation, with more than a quarter (4) believing the industry performance was poor, stating development and products being sourced overseas as reasons for this point of view.

○ Government & Industry.

Government policy and regulation have been identified as having a prominent influence on the position of the industry in New Zealand. Poor education, low skill set, integration between the trades, regulation, and legislation of the trade limit the market from establishing practices and hold back the industry from adopting new technologies. Other factors that influenced the position of the industry were the lack of government incentives to innovate, geographic location, and market size.

○ Motivation.

Most participants agreed that a lack of funding and a lack of incentive to innovate were the main issues preventing clients from exploring more energy-efficient and alternative solutions. Most participants noted the temperate environment, which much of the New Zealand population occupies, with temperatures rarely venturing into extremes, as a limiting factor to exploring alternative solutions. In addition, some participants mentioned a cultural change underway presently where houses are unoccupied for long periods of the day and require different and adaptive solutions.

○ Areas in which New Zealand is well-positioned.

A participant believed that the New Zealand market was in a good position. This is attributed to the understanding that New Zealand is on par with the rest of the world when it comes to single-split technology. Additionally, New Zealand has an established and reliable electrical grid, which bodes well for future electrification. Electrification was identified as the future direction that the world was heading towards.

- Interview Question Two: Of the identified technologies used in other regions of the world, with regard to your experience, please rank from most viable to least viable in New Zealand. Please elaborate on any strengths and weaknesses of these identified technologies and any factors that may affect this ranking.

The participants first identified if they were aware of the technologies and the advantages and disadvantages of each application; they then provided insight into viability in New Zealand with a yes or no answer before ranking the options from most viable to least viable (Table 2).

Table 2. Participants' rankings of the selected technologies from most viable (1) to least viable (8).

HVAC&R Technology	Participants Ranking											Average
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	
Earth–Air Heat Exchangers (EAHE)/Earth–Air Tunnel Heat Exchanger (EATHE).	8	6	7	6	8	8	8	2	8	5	3	6.27
Thermal Buoyancy Principles (Solar Chimneys, Domed Ceiling with Cupo- las, etc.).	3	2	8	5	7	5	4	8	3	7	6	5.27
Geothermal Heat Pump (GHP)/Ground Source Heat Pump (GSHP).	6	8	5	4	6	4	3	6	6	2	8	5.27
Foundation/Slab Heat Exchangers (FHX), Geothermal Energy Pile (GEP).	7	5	3	1	3	7	5	7	5	3	7	4.82
Wastewater Heat Recovery (WWSHP)/Wastewater Heat Exchangers (WWHX).	2	3	4	2	5	2	6	4	7	8	5	4.36
Photovoltaic Thermal (PV/T), Hot Water Heating	5	7	2	8	4	3	2	1	4	6	2	4.00
Material and Design	4	4	6	3	1	6	7	5	1	1	4	3.82
Airtightness, Solar, and Heat Recovery Ventilation retrofits.	1	1	1	7	2	1	1	3	2	4	1	2.18

After the ranking, the participants were then given the opportunity to describe their reasons for this ranking. The awareness and viability of each technology are depicted in Figure 1.

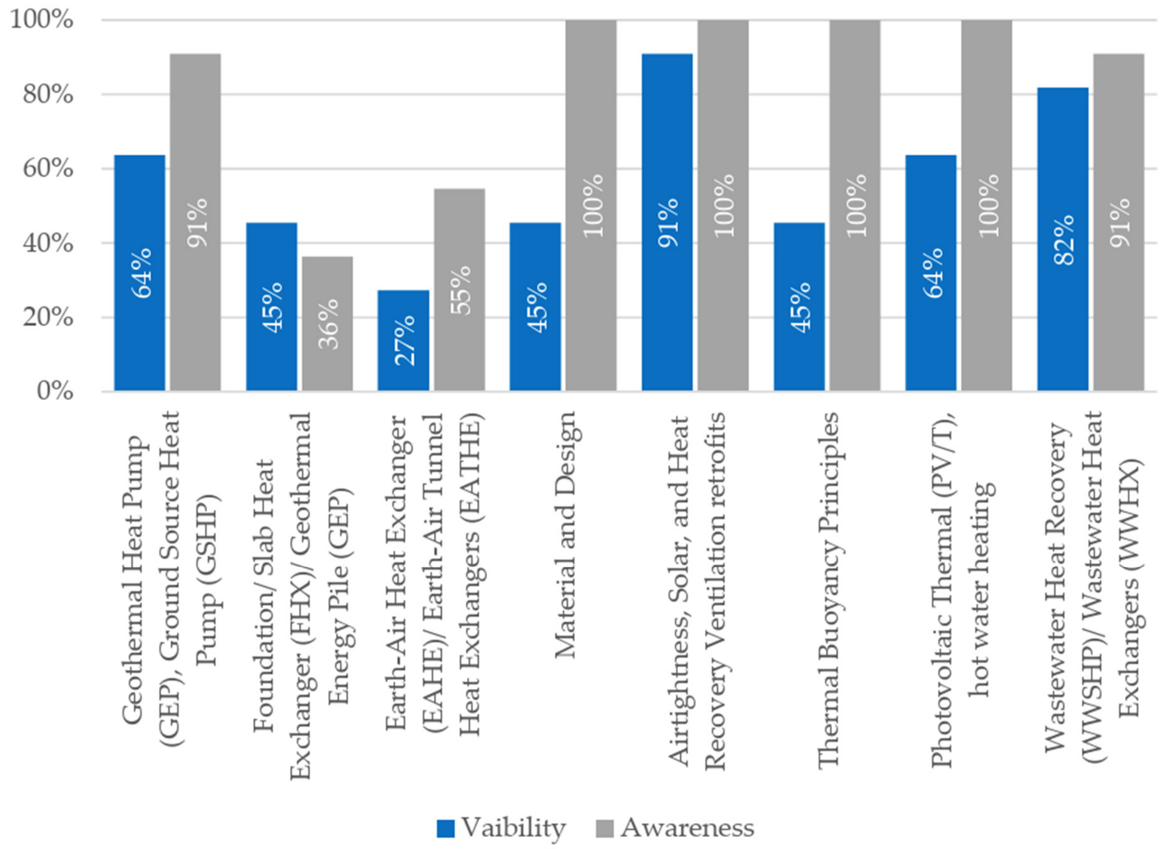

Figure 1. Viability and awareness of technologies by participants.

A summary of the themes derived from their reasons is described below.

- ○ Geothermal Heat Pump (GHP)/Ground Source Heat Pump (GSHP):

It has a higher COP than a normal air-to-air heat pump and is widely scalable, so huge efficiencies can be found there. The participants stated that the requirement for land, the cost of earthworks, the cost of consent, and compliance would limit technology in New Zealand. The demand for this in New Zealand is unlikely to be high, and this is unlikely to drive the price down into the realm of the mass market. Temperature differential in New Zealand was also stated as being too low in the coastal areas, with more temperate climates; however, there is a possibility that conditions may exist in areas such as the Central Plateau and in the Southern Alps.

- ○ Foundation/Slab Heat Exchangers (FHX), Geothermal Energy Pile (GEP).

Likely viable in areas south of Wellington, New Zealand. Issues stated included seismic concerns, high risk, limited available energy, and the cost to implement. This solution had the lowest awareness rating of all technologies. However, this was not reflected in the perceived viability when the concept was described.

- ○ Earth–Air Heat Exchangers (EAHE)/Earth–Air Tunnel Heat Exchanger (EATHE).

Whereas aquifer water could potentially be used to recharge the system, the system would come with some setbacks, including low ΔT, high cost associated with groundwork, consent, operation, and a high water table.

- Material and Design.

Participants felt that the principles were viable. However, the lack of access to proper materials is limited or incurs an inflated price. The principles covered would be more suited to the alpine or colder regions of New Zealand, such as the Central Plateau and the Southern Alps. Poor insulation in the existing housing stock would require attention prior to any further thought.

- Airtightness, Solar, and Heat Recovery Ventilation retrofits.

Ranked the most viable in New Zealand by Yes/No, 91%, and by scored ranking. The strengths mentioned include that it would be effective in reducing humidity in temperate climates and address the need for better ventilation. Weaknesses to implement included poor insulation in the existing housing stock, high cost, low efficiency, and the requirement for specialist design to be an effective proposition for the unique design characteristics of the existing New Zealand housing market.

- Thermal Buoyancy Principles (Solar Chimneys, Domed Ceiling with Cupolas, etc.)

This could be a good option if the heating of the roof structure could be utilised more. However, the cost to mass implementation is too large, cultural design principles tend away from this solution, and a lack of familiarity, education and experience to get the system to operate as intended drives up the installation costs.

- Photovoltaic Thermal (PV/T) and Hot Water Heating.

Photovoltaic panels have succeeded solar panels in the New Zealand market. Substantial momentum existed in technology through the mid-2010s. However, poor insulation led to inefficiency, coupled with high maintenance costs, and the payback period became inflated. Photovoltaic panels are now a more viable option for this application; however, storage and synchronisation of high-demand peaks and available energy production limit their feasibility. Thermal integration of panel cooling was not recognised.

- Wastewater Heat Recovery (WWSHP)/Wastewater Heat Exchangers (WWHX).

This technology ranked the second most viable to the interview participants when asked if it was viable or not viable, with 82% stating viable and placed fourth in the scored ranking. All participants deemed the technology to be an economically viable option; however, they stated issues with implementation when considering that the wastewater network is governed by local councils, which may include legal concerns regarding public asset use.

- Interview Question Three: Are there any key requirements, legislation, technologies, or infrastructure that New Zealand lacks that would support improving HVAC&R system efficiency?

- Government, Regulation, and Authority

Many participants identified legislation as an area that needs to be improved to support improving system efficiency. The main concern raised regarding legislation is the lack of regulation in the HVAC&R trade. Two things that were identified as should be provided are standard guidelines for installation, which are currently not available to the market, and more government incentives.

An idea that some participants recommended as implementable in New Zealand was mandatory Operational Efficiency Labels on buildings. Described as a "Carrot and stick" approach that would generate incentives for people to invest in improving building energy performance rather than adopting a prescriptive approach. It was mentioned that this is common in Organisation for Economic Co-operation and Development (OECD) countries, Europe, and Australia; however, New Zealand only has voluntary schemes.

- Industry Standard, Education, and Competency.

The participants felt that the professional environment in the HVAC&R industry is lacking. The reason for this belief is that the industry is unregulated, and with this, there is no requirement to upskill or continue education beyond the minimal acceptable standards. Some participants felt that this further results in below-satisfactory levels of installation and sub-optimised, energy-inefficient installations and solutions.

Availability and accessibility to technology are further issues. Despite its willingness, the industry in New Zealand does not have access to the latest global technology due to market size and demand, so it faces the challenge of being unable to train a suitably experienced workforce to deliver innovative technology to the market successfully. Furthermore, a lack of regulation makes the prospect of introducing new innovations risky to a manufacturer, so there is hesitancy.

When asked why these issues are present, the reply was that the industry body was either not big enough or strong enough to implement change. This is the belief that there is an underlying attitude that encourages the industry to solve its own problems, rather than adopt processes or solutions that have been successful in similar climates and situations.

- Motivation and Market factors.

The lack of manufacturing or infrastructure places a reliance on products and technology being imported into the country. This factor makes innovation unaffordable. Innovation, at the scale of the New Zealand market, is a risky and unprofitable venture, driving a low incentive to innovate.

- Areas for Improvement.

Areas in the industry mentioned by participants that were in urgent need of improvement are ventilation and dehumidification, air quality in buildings, and the adoption of more green building trends.

- Interview Question Four: Please give me your opinion on New Zealand's readiness to assimilate new technologies.

- Attitude toward innovation.

Despite a quarter of participants (3) stating that the industry was willing to explore new or innovative solutions, particularly in the high-end market, the consensus was that the New Zealand industry was not ready. Financial constraints, government policies, and lack of access to new technology are all attributed as reasons that the market is not ready.

- Industry Governance.

Training and education were identified as the biggest issues when it comes to trying new things. There is an agreement that there is a skills gap in the industry, from the bottom all the way to the top. This shortcoming is not exclusive to trade but includes the client aspect, as the consumer is neither educated nor aware of the alternative or how these may affect their building, operational costs, or indoor air quality. Participants mentioned that there is a gap in knowledge and experience when it comes to writing and implementing effective legislation, initiatives, and building standards. Some stated that this is exacerbated by New Zealand's relatively short government term, resulting in potentially volatile building policies.

- Motivation and a need to change.

Motivation is predominantly determined by financial flexibility to explore alternative solutions. In the current market, and for much of the population, there is hesitancy and a lack of finance to explore alternatives and step away from tried and tested solutions.

Historical data are unavailable to depict return on investment, incentives to innovate, and the hierarchy of fund allocation to different trades in the building process, which affect the availability of capital to be directed to explore alternative options.

- Direction of the Market.

A small number of participants believed that the New Zealand industry was in a good position for the adoption of new innovations and technologies. With the energy grid in New Zealand being heavily electrified, New Zealand stands well to adopt new technologies as the global trend heads toward renewable energy electrification.

- Current situation.

There is no agreement that new technologies are the solution; however, there is agreement that access to technology is limited. Technology is not the only thing that is limited, from basic building materials and insulation through to materials specific to industry, such as low Global Warming Potential (GWP) refrigerants. "90% of the required housing stock in New Zealand is already built", so there lies a problem that a solution is required from the approach of improving the quality of air in these buildings rather than focusing purely on new construction projects.

5. Discussion

This work aimed to explore global alternative energy-efficient HVAC&R solutions for New Zealand and establish market readiness towards integrating new, innovative, and sustainable solutions.

The first part of the research identified alternative HVAC&R solutions that reduce traditional installations' energy demand and establish their viability in the New Zealand Market. The second part of the research looked at what underlying factors influenced the readiness of the market towards integrating new, innovative, and sustainable solutions in New Zealand. The findings are discussed below.

Viable Solutions

Airtightness, solar, and heat recovery ventilation retrofits were the most viable solutions, according to the participants interviewed. It is interesting to note that the strengths of the system, being that it reduces indoor humidity in temperate climates and provides better standards of ventilation to buildings, are in line with some of the identified areas that some participants stated as being urgent areas for improvement. It is essential to realise that despite this solution being noted as the most viable, the weaknesses identified by participants and in the literature are in line with some of the issues the industry currently faces in New Zealand [67]. These are expensive to design and implement, and poorly insulated homes with complex designs remain challenges that will affect the solution's viability in the market. Regardless of this, the system was still identified as the most viable, both in terms of ranking and by a yes or no answer.

Materials and Design, as a category, did not rank highly on viability when asked if it was a viable strategy or not. However, it was the second most feasible option scored. The category included a wide variety of material and design principles, of which some of the participants had negative viewpoints or were questioned on whether they were implementable, namely, phase change materials, stating access to materials, cost of the product, and unavailable performance data [68]. Trombe walls were mentioned as expensive propositions due to the costs associated with the design and the lack of skilled professionals to implement this type of system successfully. These themes align with other themes identified in other interview questions, as discussed later. Other principles, such as using better material, reflective surfaces, insulation, and roofing materials, were highly praised, with one participant noting that the solutions "align with the Zero-Energy Building (ZEB) methodology, which should be integrated more into the New Zealand construction industry". This mismatch of opinions in the category may explain the high viability ranking, although further research should be pursued regarding specific methods and technologies.

Photovoltaic, thermal, and hot water heating, despite participants being vocal about the failures of solar thermal technology in New Zealand, remains a viable option through photovoltaic technology as a substitute. Access to material remains a limiting factor, as with most new technologies in New Zealand, which increases the cost and limits accessibility to a large percentage of the population. Peak electrical generation in summer, energy storage requirements, and low sun hours during winter were all disadvantages identified that aligned with the literature. Although the application of hot water heating was deemed viable, further integration with panel cooling, heat diversion, and subsequent indoor heating is an unfamiliar application for most participants; however, it would likely not negate the identified disadvantages.

Wastewater Heat Recovery (WWSHP) and Wastewater Heat Exchangers (WWHX) were the second most viable options by yes or no opinion; however, they scored fourth when ranked against others. The participants identified issues regarding legislation and implementation of these systems as potential issues in New Zealand; this is in line with limitations identified in the literature. Despite not all being aware of the technology, most participants express positivity towards this solution, yet not one ranked it first.

Geothermal applications were deemed among the least viable of the technologies identified for this research. Although one of the cleanest and most stable alternative energy sources was identified, the results show that the participants do not favour the technology. Cost of groundwork, access to land, council consent, and seismic concerns were all identified as deterring factors towards geothermal in general. Where the cost of groundwork was identified in the literature as being a disadvantage, other issues mentioned were not and could be specific to the New Zealand context. Participants were aware of the technology; however, most associated geothermal with hydrothermal principles associated with the New Zealand Taupō Volcanic Zone, or Kawerau region.

Foundation/Slab Heat Exchanger (FHX) and Geothermal Energy Piles (GEP). Despite having the lowest awareness of all technologies, its viability by ranking and yes or no was neutral, seismic concerns were raised, and statements about favouring locations south of Wellington were made. These statements do not align with the limitations identified in the literature, so further research into these concerns will be required.

Geothermal Heat Pumps (GHP) or Ground Source Heat Pumps (GSHP) have certain general shortcomings. It has been suggested that the temperature differences typical of temperate climates may not be ideal for these systems, and that they are better suited for colder regions such as the Southern Alps and Central Plateau. While this perspective is not widely documented in the literature, other shortcomings are noted. Themes that emerged from subsequent interviews included limited experience and skills in implementation, high costs of the technology, and a lack of coordinated efforts among different trades during installation.

The participants stated that thermal buoyancy principles are widely used in many applications in New Zealand, particularly warehouse structures. Although there are examples of this theory in non-warehouse installations, the temperate climate with lower sunlight hours and high humidity levels is not conducive to an effective solution. This finding reflects the specific geographic locations of the literature; further research into the application of the principle in temperate climates in non-warehouse buildings should be conducted.

Where thermal buoyancy principles were related to design, such as domed ceilings with cupolas and solar chimneys, participants stated that pre-existing biases towards established design principles tended to dictate the direction of structural design and construction techniques in that regard. This was not considered or reflected in the literature; in addition, unfamiliar practices lack skilled individuals and so incur higher installation costs.

The Earth–Air Heat Exchanger (EAHE)/Earth–Air Tube Heat Exchanger (EATHE) was the least viable option, both by opinion and ranking, for the reasons associated with geothermal as a category and issues identified with temperate climate conditions, particularly humidity, groundwater, and bacterial spores developing in the system. Solutions to overcome these issues were not identified in the literature, and further investigation would be required to validate these statements.

Despite the literature showing that all of the selected technologies are capable of reducing the energy loading required by traditional HVAC&R systems, their viability was very specific to New Zealand's climate, industry, legislation, and culture. There is an implication when assessing how to implement an alternative solution to consider these factors in the feasibility and subsequent payback period assessment.

- Assessing the New Zealand HVAC&R market's readiness towards improving efficiency and innovation.

Some prominent themes emerged when trying to establish market readiness toward integrating new, innovative, and sustainable solutions in New Zealand. The government's influence, education, finance, access to technology, and underlying cultural themes were recurring.

The first thing to consider is New Zealand's unique geographic situation. The country is relatively isolated from most of the world, with its nearest trading partner being Australia. The country has a small population, and despite being a developed country, the HVAC&R industry is small, and so is the market. Due to these factors, manufacturing is almost non-existent, the capital available in the market, and the demand for research and development of product lines to meet the country's environmental and market conditions is not a scalable endeavour and would not likely be able to compete with global technology and manufacturing.

Because of this, the HVAC&R industry in New Zealand is almost forced to purchase and import materials and technologies from overseas. A secondary effect of this is that the industry is forced to follow the direction of Australia for product lines and Europe for legislation and technology direction.

New Zealand has a temperate climate, no dry season, and a warm summer climate (Cbf). This climate does not experience extreme temperatures or significant variations across the year; however, due to the maritime influence, high humidity does have a considerable impact on the nation's requirements.

Education in industry has a large impact on the ability to implement new or innovative technologies into the market. Some of the reasons behind the lack of industry skill set can be attributed to the restricted availability or access to new technology. Because of the difficulty faced by the industry in acquiring technology and materials, there is not enough demand to push education and skill development forward to a point where there is an adequately skilled workforce to complete installations to an appropriate level.

There are no industry-enforced standards or regulations for working in the HVAC&R trade in New Zealand. Unlike other trades, electricians, plumbers, gas fitters, etc., where there is a requirement to be licensed and registered, the HVAC&R industry does not require a recognised qualification. There is a very limited professional environment in the HVAC&R trade, and with this, there is no requirement to upskill or continue education beyond the minimum acceptable level. This promotes the minimum standards to be practised. This results in the New Zealand market being a higher-risk environment for manufacturers to operate in, further leading to possible hesitancy in introducing new products into the market. Where industry participants repeatedly stated that the industry should require better professional standards, further suggestions were made for using standard guidelines for installation.

Lack of education is not limited to industry professionals. The opinion of some participants is that clients, building owners, building operators, landlords, and people associated with selecting the mechanical services to be installed or designed for a structure are typically not aware of the performance or efficiencies available by alternate solutions. Furthermore, the cost of consent associated with alternative and innovative solutions deters the appetite to innovate. The participants recommended (1) more government incentives for projects aimed at improving energy efficiency and (2) building operational efficiency labels to promote public awareness and generate investment in energy efficiency.

While there seems to be an attitude and willingness toward innovation and energy efficiency in New Zealand, the results show that the market's priority needs regarding efficient HVAC&R systems do not reflect this. Where motivation can be spurred by the methods suggested above, a significant proportion of participants agreed that there were some areas of concern in the New Zealand industry, particularly around industry standards for dehumidification and ventilation. Where this would require further investigation, it is beyond the purpose of the research.

The implications of these findings are that the industry has some challenges that will need to be addressed if improvements to energy efficiency are to be prioritised; these challenges include overcoming poor education, lack of regulation, lack of initiatives, and lack of access to new technologies.

6. Conclusions

New Zealand's temperate climate was a common feature when discussing the viability of all technologies/solutions. With a large percentage of the population occupying coastal and temperate climates, humidity, relatively shallow differences in high and low temperatures, and low ΔT negate the requirement for integrated solutions in most circumstances. Due to geographical isolation and small market size, access to technology is somewhat limited, coupled with low demand, which results in installation costs being high. Legislation, consent, and a lack of skilled workforce further led to increased risk and projected costs.

The New Zealand market is not in a good position to adopt new or alternative solutions. There is a willingness toward innovation; however, the ability to explore new technologies is reserved for organisations or individuals with financial means. Lack of manufacturing, relative market size, and industry organisation have resulted in high installation costs, supply issues, and a position of followers on the global stage. Key issues that put the industry in this position are a lack of industry regulation, professional qualifications, and inadequate standards.

Recommended and most viable technologies or strategies by industry opinion to improve the energy efficiency of HVAC&R systems were as follows:

- Airtightness and Heat Recovery Ventilation Retrofits.
- Material and Design (Roof Insulation/Materials/Reflective Surfaces/Insulation).
- Photovoltaic Thermal (PV/T) and hot water heating.
- Wastewater Source Heat Pump (WWSHP) and Heat Exchangers (WWHX).

Where other innovative technologies exist (not considered in this research), recommendations should be made to assess the specific characteristics of the solution to New Zealand's climate, industry, legislation, and culture and to consider the industry's ability to deliver successful installation. Further recommendations can be made to evaluate the efficiencies provided by the selected technologies of this research, where examples exist within New Zealand, if available.

Before the implementation of any incentives, further study should be conducted into the success of other countries' government initiative programs and their effectiveness in improving the energy efficiency of HVAC&R systems.

Further areas of study would include an investigation into effective industry regulation and policy, along with the level of qualifications to improve the quality of installations before any recommendations could be made in this regard.

Also, studies on other countries would provide a comparative analysis of barriers to the implementation of innovative solutions and the development of specific strategies to overcome the identified barriers. The authors note that a considerable proportion of participants were based in Auckland, New Zealand, and Christchurch, New Zealand. It was mentioned that the different climatic conditions of the Southern Alps and Central Plateau regions of New Zealand may be more suited to some technologies identified in this research. Involving participants with expertise in these regions would have provided a deeper insight into the situation. Throughout the research process, information became available about some technologies that had recently been implemented in some construction projects around New Zealand; although data was requested, it was either non-existent or not available at the time of publication. This data would have been beneficial to the project. Further limitations would be the input of the customer or client regarding attitudes toward innovation, energy efficiency, and motivations.

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