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Adaptive Reuse of Chimney Flues in Historic Buildings in New Zealand

Rory Greenan,

[a] *Trinity College Dublin, Dublin, Ireland, greenar@tcd.ie*

Abstract:

Thermal performance in New Zealand Building Code lags well behind the European Union and Irish energy policy, which identify the impact the built environment makes on energy use. In New Zealand, improvements to existing buildings are key in meeting the need for low energy buildings. Evidence implies that the global climate is changing with potential increase in temperatures across the world. Thus climate change may have an extensive effect on the thermal performance of the built environment and on any measures to improve their performance. Simulations are applied to a historic building in Christchurch, New Zealand i.e. Canterbury College, former 'Registry Office' building. It was designed by Collins and Harman and completed in 1916.

In this paper I Investigate the potential building performance enhancements that can be harvested from existing chimneystacks, by way of adapting the redundant flues as air pathways for natural ventilation. There is potential for heat pump coils to impale exhaust air flows, recovering heat. Air to water heat pump can supplement the heating loads required for the building. These pathways can also be used to improve indoor environmental quality (IEQ) by improving indoor air quality (IAQ) and thermal comfort. Future climate change uncertainties are factored into future scenarios allowing for the ventilation flues to make use of night-time cooling and exploit the thermal mass of the historic building. The base case building that has been selected has masonry construction with heavy thermal mass which is altered through digital modelling to simulate a light weight timber frame building. Varying uses for the buildings are examined with future climate change scenarios applied to the weather for the region.

Keywords:

ECOS Conference, Energy, Sustainability, chimney, flues, natural ventilation, heritage, conservation

1. Introduction

A massive repair initiative is being implemented due to the aftermath of Canterbury Earthquakes, in New Zealand's South Island. Thousands of buildings are in need of significant repair and hundreds have been demolished or are structurally deficient, particularly in Christchurch's Red Zone, where the ground has subsided and is unsuitable for building use. A clearance programme is in effect.

The architectural element most under threat of extinction is the chimney stack. Thousands were damaged and hundreds beyond repair. This paper examines the paradox the chimney finds itself in, with a contemporary policy of reducing its primary function i.e. to exhaust gases and smoke from combustion of organic and fossil fuels to provide heat. This policy is driven by the poor air quality and smog produced in the city due to chimneys, transport and the geography.

The repairs have highlighted significant issues with regards to the structural building code conflicting with replace with like for like. Significant chimney replacements are cosmetic and aesthetic rather than true repair and replacements, particularly in buildings which are considered to have heritage value. The introduction of steel and brick slips with double skinned metal flues is common.

Analysis is carried out on the alternative future of the chimney and of its contribution to energy use and human health and comfort.

1.1. Context

Retrofitting of buildings is largest construction project in the world. It has been identified as an imperative to tackle climate change and reduce our reliance on fossil fuels and excessive energy use. The execution of retrofitted measures to enhance energy efficiency and performance has different levels of return both now and into the future. D.Vallero and Chris states that the need is for the professions to “evolve from the current thinking of sustainability and the primary focus on energy efficiency and high performance to the concept of regenerative design” [1]. This said with climate change uncertainties leading us to an uncertain climatic future and parallel problems of energy security, the future proofing of existing building stock is critical while tackling energy and food poverty [2]. The current context of low price of oil being caused by OPEC countries maintaining higher levels of supply with a lower global demand is distracting New Zealand from the bigger picture of tackling a global climate change policy.

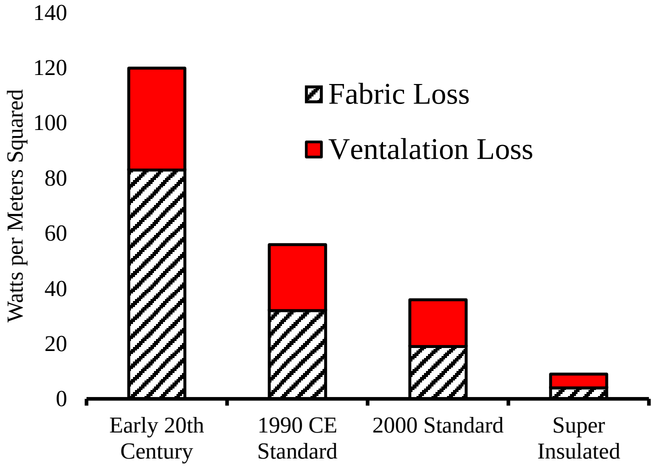
Global awareness of the substantial need to improve building thermal performance and internal environmental quality (IEQ) is growing. New Zealand (NZ) building code illustrates deficits in current NZ practice. Consequently, building skins are a critical element in building and its construction technology due to their contact with the outdoor environment and with surface temperatures rising above 80 ºC dependent on location, direction and time of year. The implementation of active building envelope systems is required to meet the demand and to provide building envelopes that reduce the heating and cooling loads, complementary to the function of buildings [3-6]. Thus heat loss from buildings needs to be captured and returned into the buildings system and the buildings unwanted gains can easily be expelled from areas it is most problematic.

Conventionally, ventilating buildings was to exhaust unwanted water vapour and the various pollutants of the occupants and materials, e.g. its fabric finish and furnishings. Ventilation was provided through a combination of fenestration and designed ventilation, driven by wind and temperature difference. The low quality of design and construction practice of building skins allowed uncontrolled filtration (air leakage) i.e. infiltration and ex-filtration and un-designed ventilation [6-8]. A significant proportion of heat losses in buildings is via ventilation and filtration, with historic buildings being particularly susceptible. Retrofitting of historic buildings are particularly prone to defects associated with poor practice. Establishing the amount of ventilation required to provide a healthy IEQ and IAQ is problematic [9]. Since it is difficult to estimate the ventilation impact, the concept of energy use by way of ac/h is frequently indeterminate. Consequently ventilation design is a complex task requiring consideration to location, climate, use, air tightness and users, often coupled with inadequate datum.

Continuous evolution and innovation in construction technologies have enabled the development of buildings of an unparalleled scale and created a requisite of the implementation of ‘Air-Conditioned buildings’. Mechanical systems HVAC provide heating, cooling, filtration and air quality requirements.

Dependency on technology and mechanical HVAC systems was due to architects increasingly pushing the boundaries of contemporary building design to meet the ever increasing demands of clients. This made significant increases in a buildings energy usage. Often systems were located distant from the external environment and had requirements to condition air repetitively around a building. Sick-building syndrome and building related illnesses started to develop and are connected to mechanical systems which usurped the natural ventilation approach [5,6]. Some Architects encouraged naturally ventilated design in their buildings through the use of atria and ventilation pathways and passive stacks. However, these building designs are complex, perceived at increase capital costs, and are very location specific, meeting local climate needs i.e. Bespoke and specialist. [10]

Figure 1: Heat losses of typical dwelling types from different periods of construction. The proportion of fabric and ventilation heat loss illustrated is CIBSE guides based with general agreement with findings from BRANZ.



Contemporary buildings are progressively becoming air tight 'Design tight, Ventilate right' being the guiding principle now at the forefront of building construction. These principles guide the application and designers' innovation has evolved mechanical delivery systems with improved performance, including heat recovery and filters specific to reducing energy consumption [7,11]. This has resulted in mechanical ventilation strategies returning to contemporary building design, due to their advantages in filtration and heat recovery, with hybrid systems being developed to combine mechanical and natural ventilation.

Currently a wide continuum of ventilation resolutions from 100% natural to completely air conditioned are obtainable. In a similar effort to Wales and England, recent revisions to Part L of the Building Regulations for Ireland have set new challenges for building design with the aim of reducing carbon emissions through building energy performance. New Zealand's Thermal performance within the building code is currently behind the 1997 level of UK and Ireland [12,13]. Air tightness testing and post occupancy certificates will become important factors at design level in New Zealand. Designers, clients and users need to grow aware of the prominence of energy performance in buildings, the potential savings and enhanced user productivity. BRANZ is leading research in NZ and the introduction of ventilation heat recovery is at the fore front of design, which is a mechanical ventilation system, susceptible to electrical and or mechanical failure and self-polluting if not maintained adequately.

The exhaust air heat pump is an alternative technology being utilised. With a similar approach as the passive stack ventilation with the exception of exhaust air mechanically drawn from the wet areas, with a heat pump recovering heat from the air and input to water [14-16]. The system can supplement the heating required for hot water domestic use or the heating loads. This paper looks at the possibility for chimney flues in an existing historic building stock and analyses the air flow which could be used for heat recovery. It is also examines them for night-time cooling effects and IAQ benefits [15,17].

1.2. Natural Ventilation Principles

Air flow is caused by natural ventilation due to two factors, wind and temperature difference. For temperature difference only, also known as buoyancy force or stack effect. The effect is caused by a difference in air density (created by a temperature difference between the external and internal air).When the outside and inside air temperatures are almost equal (e.g. during the summer in New Zealand), the stack effect is reduced.

Wind driven ventilation is caused by differing pressures on surfaces. The pressure differential across a building envelope is affected by the building's form and orientation, in addition to the neighbouring terrain and its obstacles. During the summer, wind turbulence is the main driving force of natural ventilation in buildings as external temperatures approach internal temperatures reducing the stack effect.

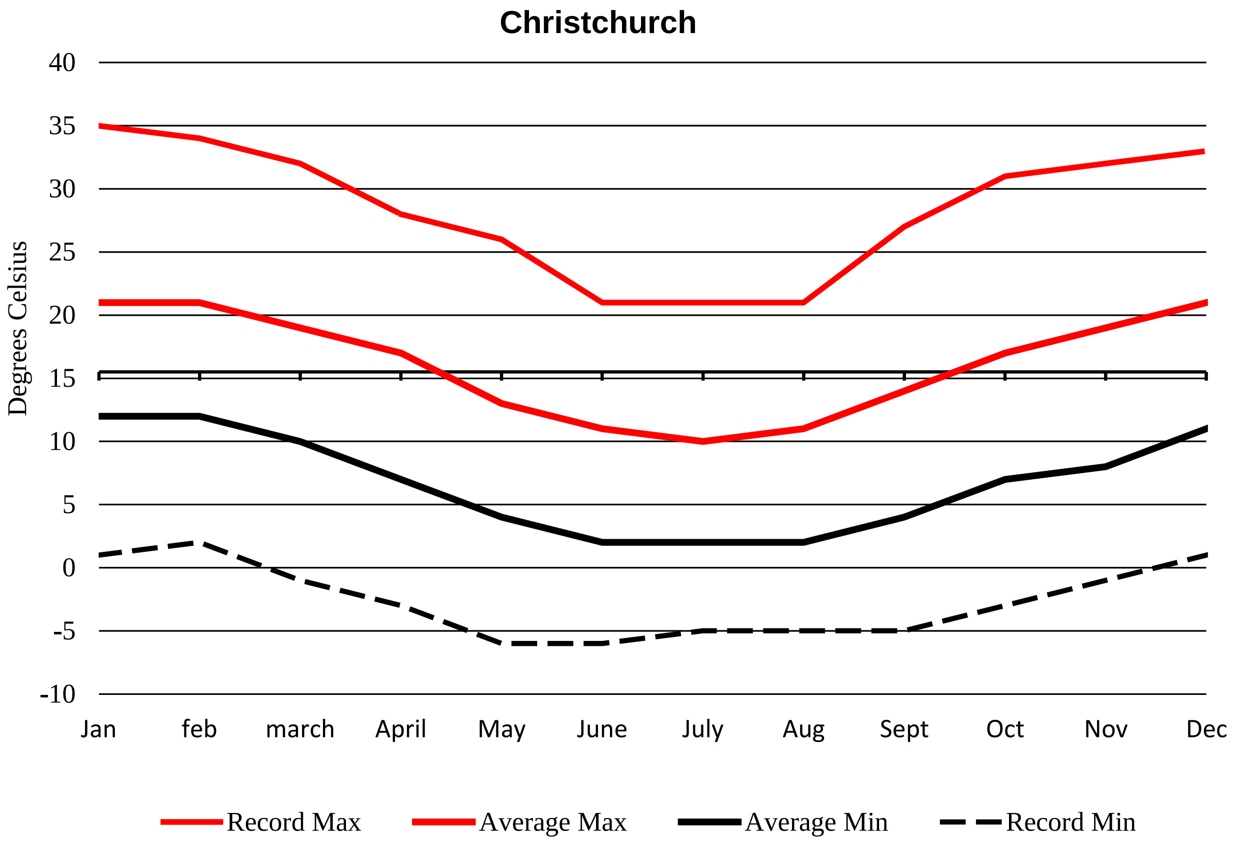
2. Climate

Christchurch has a temperate climate with moderate precipitation A typical external design temperature of 15.5 °C is used since internal temperatures are usually 3 °C above that of the external air. Although this is below the base design set point of 20 °C it is a good indicator of external temperature for internal comfort. (This is the basis for the degree day method).

2.1. Christchurch

Christchurch's Dry Bulb air temperature record Figure: 2 Note the temperatures are experienced at an average range from 2 °C to 21 °C. The winter's average minimum temperature remains above freezing. This climate purely by the temperature data alone indicates a mild temperate climate which requires heating during the winter season and some in the spring and autumn period. Note 15.5 °C temperature line illustrates the winter with temperatures all below a typical outdoor design temperature of 15.5 °C and a summer with a balance on the 15.5 °C design line.

Figure 2: Graph of Dry Bulb Air Temperature Record of Christchurch New Zealand. Data from BBC



2.2. Climate Change

Current models predicting future climate change scenarios have many weaknesses and therefore its effect on local weather are uncertain. New Zealand research predicts slight warming in the Christchurch area and an increase in precipitation. With the prediction of the Gulf Stream weakening in the North Atlantic, thermohaline circulation from 15%-25% by 2100 will help mitigate the warming of north Western Europe i.e. Ireland the UK. The opposite is the case for Australasia as the thermohaline circulation aids cooling to New Zealand. It's slow down or shutdown could add an estimated 1-2 °C in addition to that expected to climate change via greenhouse effect prediction models. For this paper cooling transported towards New Zealand via the thermohaline circulation is assumed as not changing. Not one of the global climate models included in the IPCC Third

Assessment Report indicated a complete shut-down of the thermohaline circulation near NZ by 2100" [2,18].

Predictions of the future may be worse than the modelled scenarios predict, therefore in this building case study, more extremes of cooling may be required for the building and are added to the study to see the effect on the performance for a less likely future, giving a more informed understanding of the potential performance of the building and its chimney flues. In this paper, temperature and weather data for Hobart is proposed to simulate climate change by 2075.

2.3. Hobart

To account for climate change uncertainties it is obvious that colder climates will require more heating than the current Christchurch context, whereas expressing higher temperatures will require cooling or in the case of natural ventilation, night time cooling. It is proposed to use Hobart which has milder winters and slightly warmer summers than today's Christchurch weather.

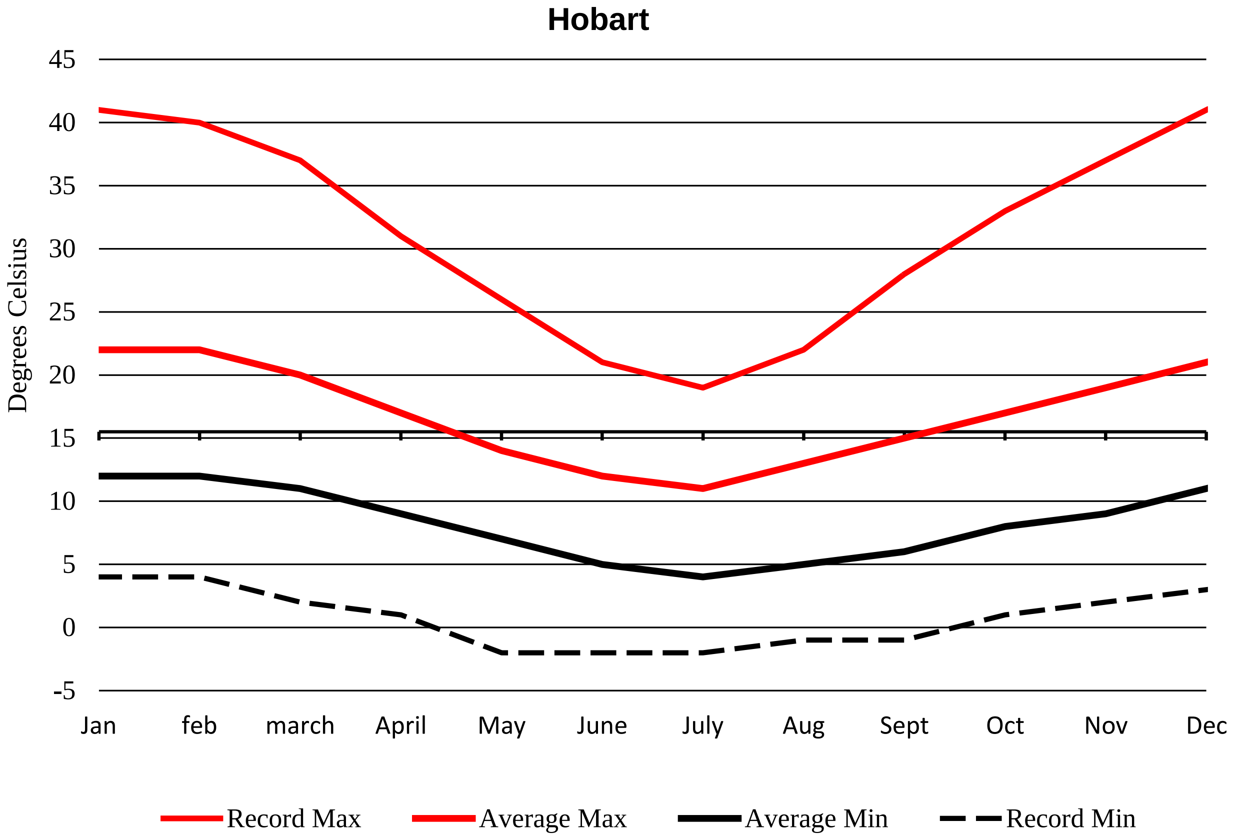


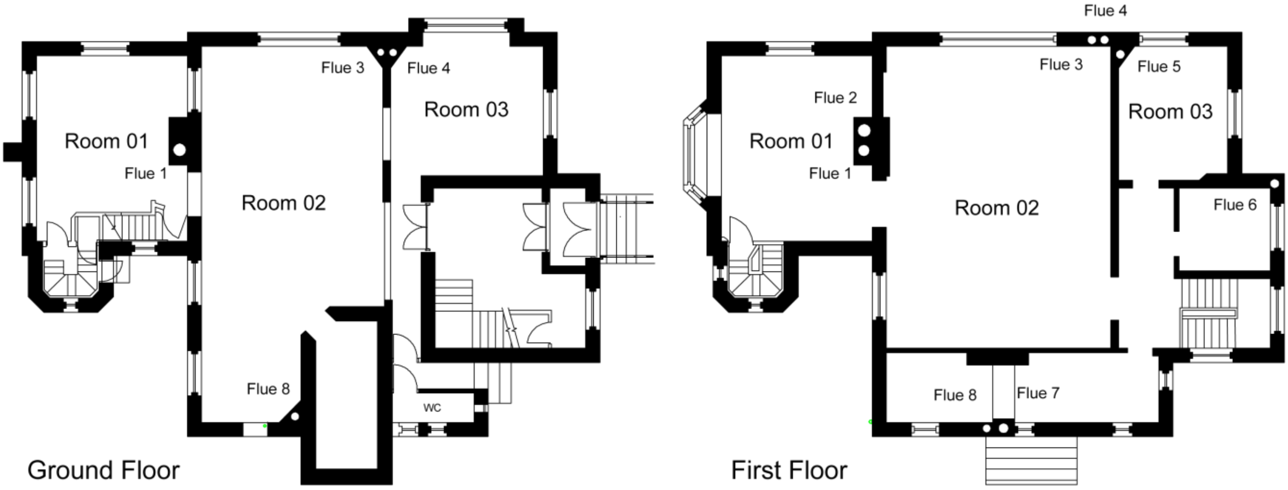
Figure 7: Air Temperature Record of Hobart, Tasmania, Australia

3. Case Study

Canterbury College's Registry building was built in 1916 to accommodate the College's administration staff, with a small extension added in 1926. It was designed by Collins and Harman and at the time it was considered a plain building. Prior to the earthquakes and since repair the building is in commercial use. The Registry is a NZ Category 1 heritage building. It was decided to examine the building with two uses i.e. as residential apartments and as an office for an office business.

The base case has blocked fireplaces and compared with open fireplaces of different variants for the building, it uses and times i.e. 2015 and 2050. The building is constructed of masonry elements which include bluestone masonry walls and Oamaru stone. The floor areas are 168m^2 ground floor and 162m^2 first floor with a floor to ceiling height of 3.6m for both floors. This provides for quite a large air reservoir.

Figure 8: Floor Plans of Registry Office



3.1. The Building

The building is of masonry construction with external walls of 450 mm, lime plaster rendered to the internal facades. The internal walls are 250 mm lime plastered. The floors are timber construction un-insulated with lath and plaster ceilings. The ceilings are lime plastered and the roof space (Attic) is partly insulated. All the original windows are iron frames, gothic in style and are in place with opening lights in the centre. The building is modelled for heavy thermal mass and lightweight thermal mass ie. masonry construction and timber frame respectively. In the scenarios with windows in use, they are set to open at 23 °C and be fully open at 28 °C.

3.2. Apartment Use

The dwelling is set up for an apartment on each floor. The occupants are assumed to be a professional unit of 4 i.e. two couples, four adults. The 3 earning adults leave at 8am and return at 6pm during working days. The occupancy is assumed to be 4 at weekends. It is assumed a bad heating profile is used i.e. heating is on all the time at 21 °C in the living room (Room 3) and 18 °C for bed room. (Room 1 and 2). This is the case for both floors. The bedrooms are occupied between 11pm and 7am. The living room is occupied with 4 from 7am to 8am then 1 from 8am to 6pm.

3.3. Office Use

It is assumed the office opens at 8:30am and occupants arrive between 8:30am and 9am . The business closes at 6pm and the occupancies are all gone. Rooms 1, 2 and 3 are occupied offices for this scenario on both floors. 50% of the staff leave at lunchtime. The heating set point is once again 20 °C with boiler turning on at 7am and off at 6pm.

3.4. Future Scenarios

The 2075 scenarios have the same heating setting for both the office and the apartments. The difference being the weather data i.e. Hobart to simulate climate change and therefore climate change effects. For the purposes of the report it is tabled as 2075 but as climate change uncertainties are impossible to predict they are in general agreement with a medium effect of change.

4. Modelling

IES Virtual Environment 2014 software was utilised to carry out the dynamic thermal analysis (ApacheSim). This is linked to network flow models (Macroflow) and solar shading analysis (SunCast). The model is built using Model-IT representing the building, accounting for volumes and boundary conditions with detailed chimney flues and stacks in place. The occupancy and heat loads are input and the simulations run in ApacheSim linked to account for the solar penetration and network flows. Window profiles are set to account for them opening and for leakage by way of infiltration. The Thermal simulation is used to produce results for the effect the flues have on the ventilation air flow, air temperatures and air velocities, Indoor environmental quality is analysed by viewing the CO_2 parts per million (ppm). To account for potential climate change the weather data for Hobart is utilised in the model (2075). The models geographical location has no change thus solar effects are equal. These are carried out to stress the effects of the future against the optimum performing scenarios of the present.

Table: 1 of modelling abbreviations

BC	BX	V	V followed by a number	V followed by a letter
Base Case	Base Case Timber frame	Variant	Variant number Masonry Construction	Variant of Timber frame construction

Table: 2 modelling abbreviations

Letter O	Letter H	fc	fO	W
Office	Home Use i.e. Apartments	Fireplace closed	Fireplace open	Window open

Examples:

BC OfcW : means ‘Base case Office Fireplace Open and windows active’.

V3 HfO : implies ‘Variant 3 Home use Fireplace Closed, window inactive’

Va OfOW : ‘implies Variant a Timeframe office use Fireplace Open Windows active’

5. Results

Results from the thermal analysis emphasize the efficiency of the stack effect on ventilation. The ac/h is quite high with respect to contemporary design but largely agrees with that expected for a building of early 1900s. Sensitivity of different building uses and scenarios are clearly identified. From Tables 3 and 4 (note fc and fO refer to closed or open Fireplaces) the heating loads increase when the fireplaces are open, thus air flows more readily up the flue. This is true for both the office use and the apartment’s use of the building and for masonry and timeframe construction. To understand the results and the abbreviation, naming convention please read Tables 1 and 2.

Table 3. Table .Boiler Loads MWh Masonry Building

	BC Ofc	**V1** OfO	**V2** OfcW	**V3** OfOW	**V4** Hfc	**V5** HfO	**V6** HfcW	**V7** HfOW
Total	18.1	19.5	19.8	22.4	75.7	78.3	79.5	84.2

Table 4. Table .Boiler Loads MWh Timber Frame Building

	BX Ofc	**Va** OfO	**Vb** OfcW	**Vc** OfOW	**Vd** Hfc	**Ve** HfO	**Vf** HfcW	**Vg** HfOW
Total	40.2	41.7	42.1	44.7	81.4	83.7	85.5	90.2

The boiler loads show the masonry construction out performs an uninsulated traditional timber frame construction for both uses, but more so for the office use. The results suggest the masonry building requires less than 50% of the heating for office use than for timeframe. The apartments require between 4% - 6% less energy to maintain the heating profile and set point with masonry construction versus the timber frame construction.

Table 5: Number hours per year in dry bulb air room Temperature is above of 28 ^{o}C

	Ground Floor Office 8am to 6pm			First Floor Office 8am to 6pm		
	Room 1	Room 2	Room 3	Room 1	Room 2	Room 3
BC Ofc	15	27	34	34	123	61
V1 OfO	13	17	22	27	116	49
V2 OfcW	6	12	8	14	74	24
V3 OfOW	4	5	5	10	72	16
2075 OfOW	74	94	80	93	240	95
BX Ofc	224	132	259	308	104	479
Va OfO	198	109	223	263	98	364
Vb OfcW	95	65	84	131	70	121
Vc OfOW	78	50	74	108	67	107
2075t OfOW	190	180	170	228	164	233

Table 6: Number hours per year dry bulb air temperature is above of 25 ^{o}C when occupied Apartments

	Ground Floor			First Floor		
	Room 1*	Room 2**	Room 3*	Room 1*	Room 2**	Room 3**
V4 Hfc	4	0	8	20	30	38
V5 HfO	4	0	6	18	30	32
V6 HfcW	4	0	7	16	28	34
V7 HfOW	3	0	5	14	28	27
2075 HfOW	3	0	5	14	28	27
Vd Hfc	167	83	224	280	199	411
Ve HfO	157	76	192	253	196	337
Vf HfcW	101	67	107	160	141	156
Vg HfOW	91	63	101	143	139	142
2075t HfOW	92	64	102	145	147	152

*Living room

**Bed Room

The benefit of opening the flue IEQ is improved represented by the hours above critical comfort temperatures. Table 5 and 6 illustrate the different performances at critical temperatures. Table 5 showing office use and the hours above 28 ^{o}C. It is advised to keep air temperatures below 25 ^{o}C but critical not to have temperatures in excess of 28 ^{o}C for more than 1% of hours per year of operation. The 2075 results for office use shows that the 1% of hours will be exceeded for the timber frame but not for the best performing scenario selected from current trends i.e. V3 Table 5.

The apartment results in Table 6 show the hours of occupied above 25 ^{o}C. It is clear from the table the Masonry Building (results above dotted line) is out performing the timber frame structure (results below dotted line) indicating that the thermal mass is mitigating the diurnal temperature swing and the positive effect of thermal decrement. Again the 2075 sample results show the masonry building will perform in the future and the timber frame will only slightly change.

The benefit of opening the flue on IAQ is improved represented by the CO_2 ppm, with a closed fireplace blocking the flues the ppm mean is above 1000 ppm for significantly more hours than when it is open. The window operation also limits the CO_2 levels as seen in V2 compared with V3 in Table 7. It should be noted the window setting on IES is operating in synch with temperature throughout the building and in real terms would require actuators to perform this level of operation.

The results showed no hours of CO_2 above 1200 ppm this is likely due to the 1 ac/h for the building from infiltration and the large fresh air reservoir in the form of 3.6m floor to ceiling heights.

Table 7: Number of Hours CO_2 levels exceed 1000 ppm (no results yield higher than 1200 ppm)

Variant	Ground Floor			First Floor		
	Room 1	Room 2	Room 3	Room 1	Room 2	Room 3
BC Ofc	759	759	759	32	759	759
V1 OfO	214	131	759	0	759	649
V2 OfcW	13	10	8	0	90	6
V3 OfOW	11	7	8	0	6	7
V4 Hfc	759	759	759	45	759	759
V5 HfO	408	186	759	0	759	669
V6 HfcW	685	67	640	30	189	616
V7 HfOW	347	41	638	0	53	532

When compared with a study carried out on a Dublin Victorian terraced house, closed flues in that case yielded results in excess of 1500 ppm. The building in that study was smaller in floor area and floor to ceiling heights, therefore had less volume and smaller air reservoirs. This said the results in this paper are largely in agreement to those found in the study in Dublin Ireland [19], although a Victorian town house was utilised, similar indications of the usefulness of the reused flues emerged.

The temperatures in the flues reveal that when the fireplaces are open mean temperatures are significantly higher as seen in tables 8-11 in Appendix A. The flows though the chimneys are greatly higher than for closed chimneys as shown in table 12 and 13 in Appendix A, enough to make use of energy capture.

6. Conclusions

New Zealand's energy policy realises the impact retrofitting the built environment can make to reducing energy use and mitigating climate change. In New Zealand, enhancements to existing buildings are critical in realising the opportunities. Evidence is increasing implying the global climate is changing with potential increase in temperatures in the world particularly in New Zealand, facing a combination of greenhouse effects and slowing down of the thermohaline circulation. Thus climate changes may have a major influence on the thermal performance of the built environment and therefore an influence on countermeasures to improve their performance.

The simulation results applied to a historic town house in Christchurch, identifies the potential for building performance improvements that can be garnered from redundant chimney flues, by way of adapting the existing chimney stacks and utilising the flues as exhaust airways for natural ventilation. Heat pump coils have the possibility to harvest heat from stale exhaust air, via air to water systems supplementing hot water needs and or the heating loads for the building use akin to exhaust air heat pump systems, with the exception of driving forces of a passive natural ventilation system. The air ways via the flues demonstrate improved indoor air quality thus improving overall indoor environmental quality, the flues also reduce the periods of unpleasant temperatures for thermal comfort, reducing the need for mechanical cooling. Climate change uncertainties are factored into future scenarios allowing for the ventilation flues to make use of night time cooling and exploit the thermal mass of the Historic building. Further research should be carried out in a retrofitted timber frame version to compare results for the suitability of the chimney.

Acknowledgments

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Appendix A

Table 8: Flue 1 Office Use from ground floor office Room 1

Var. Name	Min °C	Min. Time	Max °C	Max. Time	Mean °C
BC Ofc	2.65	07:30,09/Jun	29.58	14:30,21/Feb	13.7
V1 OfO	3.02	06:30,25/Jun	29.58	14:30,21/Feb	13.91
V2 OfcW	2.65	07:30,09/Jun	29.58	14:30,21/Feb	13.68
V3 OfOW	3.23	06:30,28/Jun	29.58	14:30,21/Feb	14.46
BX Ofc	3.17	06:30,25/Jun	29.57	14:30,21/Feb	13.69
Va OfO	3.94	06:30,25/Jun	29.57	14:30,21/Feb	13.89
Vb OfcW	3.18	06:30,25/Jun	29.57	14:30,21/Feb	13.69
Vc OfOW	3.95	06:30,25/Jun	29.58	14:30,21/Feb	13.91

Table 9: Flue 1 Home Apartment use from ground floor bedroom Room 1.

Var. Name	Min °C.	Min. Time	Max °C.	Max. Time	Mean °C
V4 Hfc	2.55	06:30,25/Jun	29.58	14:30,21/Feb	13.77
V5 HfO	2.58	06:30,25/Jun	29.58	14:30,21/Feb	13.95
V6 HfcW	2.55	06:30,25/Jun	29.58	14:30,21/Feb	13.73
V7 HfOW	2.95	06:30,25/Jun	29.58	14:30,21/Feb	14.49
Vd Hfc	3.12	06:30,25/Jun	29.58	14:30,21/Feb	13.78
Ve HfO	3.13	06:30,25/Jun	29.57	14:30,21/Feb	13.75
Vf HfcW	3.91	06:30,25/Jun	29.57	14:30,21/Feb	13.97

Table 10: Flue 2 Office Use from First Floor office Room 1

Var. Name	Min. °C	Min. Time	Max. °C	Max. Time	Mean °C
BC Ofc	2.52	06:30,25/Jun	29.77	14:30,21/Feb	13.87
V1 OfO	4.76	06:30,28/Jun	29.8	14:30,21/Feb	15.45
V2 OfcW	2.53	06:30,25/Jun	29.77	14:30,21/Feb	13.85
V3 OfOW	4.8	06:30,28/Jun	29.8	14:30,21/Feb	15.5
BX Ofc	3.05	06:30,25/Jun	29.76	14:30,21/Feb	13.88
Va OfO	8.67	12:30,14/Aug	29.77	14:30,21/Feb	15.48
Vb OfcW	3.06	06:30,25/Jun	29.76	14:30,21/Feb	13.88
Vc OfOW	8.68	12:30,14/Aug	29.77	14:30,21/Feb	15.46

Table 11: Flue 2 Home Apartment from First Floor office Room 1

Var. Name	Min °C	Min. Time	Max °C	Max. Time	Mean °C
V4 Hfc	2.44	06:30,25/Jun	29.77	14:30,21/Feb	13.96

V5 HfO	3.31	06:30,25/Jun	29.78	14:30,21/Feb	15.35
V6 HfcW	2.44	06:30,25/Jun	29.77	14:30,21/Feb	13.92
V7 HfOW	3.54	06:30,25/Jun	29.78	14:30,21/Feb	15.33
Vd Hfc	3	06:30,25/Jun	29.76	14:30,21/Feb	13.97
Ve HfO	3.01	06:30,25/Jun	29.76	14:30,21/Feb	13.94
Vf HfcW	8.69	12:30,14/Aug	29.77	14:30,21/Feb	15.51

Table 12: Top of Flue Flow litres per second office

	Flue 1				Flue 2			
	out max	out mean	in max	in mean	out max	out mean	in max	in mean
BC Ofc	23.01	10.07	15.7	2.65	23.03	10.11	15.56	2.6
V1 OfO	23.22	10.58	15.66	2.45	28.06	13.09	15.46	1.81
V2 OfcW	22.91	10.01	15.71	2.67	22.94	10.06	15.57	2.62
V3 OfOW	34.12	11.65	33.14	2.57	48.46	13.03	47.67	2.44
2075 OfOW	34.46	12.29	29.36	2.76	48.37	12.84	51.08	2.92
BX Ofc	23.16	10.25	15.7	2.58	23.04	10.33	15.56	2.52
Va OfO	23.18	10.71	15.66	2.39	27.92	13.1	15.22	1.65
Vb OfcW	22.99	10.16	15.71	2.61	22.89	10.24	15.57	2.55
Vc OfOW	35.5	11.78	41.88	2.6	52.4	12.94	60.08	2.59
2075t OfOW	35.5	11.78	41.88	2.6	52.4	12.94	60.08	2.59

Table 13: Top of Flue Flow litres per second Apartments

	Flue 1				Flue 2			
	out max	out mean	in max	in mean	out max	out mean	in max	in mean
V4 Hfc	22.04	10.09	15.81	2.64	22.17	10.16	15.64	2.58
V5 HfO	22.33	10.52	15.77	2.49	27.94	12.94	15.6	2.01
V6 HfcW	21.99	10.09	15.81	2.64	22.12	10.16	15.64	2.58
V7 HfOW	26.94	10.54	19.87	2.56	42.14	12.88	31.12	2.18
2075 HfOW	26.94	10.54	19.87	2.56	42.14	12.88	31.12	2.18
Vd OfO	22.45	10.28	15.76	2.58	22.53	10.35	15.6	2.52
Ve OfO	22.33	10.73	15.72	2.42	27.92	13.33	15.38	1.83
Vf OfcW	22.27	10.22	15.78	2.6	22.34	10.29	15.61	2.54
Vg OfOW	34.02	10.68	33.28	2.71	51.88	13.06	56.59	2.64
2075t HfOW	33.7	10.78	33.27	2.54	51.9	13.29	56.57	2.22

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