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1_C26

Impact of WELL Building Standard v2 on the Office Building Energy Performance

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ABSTRACT

This study aims to use the WELL Building Standard (v2), an internationally recognised rating system for health & wellbeing in buildings, to perform a qualitative and quantitative analysis of the effect of wellbeing measures on an office building's energy use in three different climates. The qualitative analysis was based on literature review and engineering rules of thumb to assess the potential energy impact of WELL's 120 features. The preliminary results show: of the 59 preconditional parts; 68% have a negligible energy impact, 19% have a potential energy penalty, 5% have a potential energy benefit; and for the remaining 8% the influence varies depending on the design and local climate; of the 235 optimisation sub-points: 61% have a negligible effect, 10% have a potential penalty, 11% have a potential benefit and 18% vary depending on the design and climate. Most of the WELL v2 features influence operational policies and material selections, and therefore have a negligible effect on energy. However, certain criteria related to Air, Light and Thermal Comfort can directly affect the building's energy usage, including some features which are directly related to combating a health crisis such as the COVID-19 pandemic. According to the further quantitative analysis, individual WELL features would have an energy impact of between +9% (energy penalty) to -11% (energy saving). When combining all of the 'energy penalty features' and 'energy saving features', the result led to 53-78% more annual energy use and 20-28% energy saving, respectively depending on the climate. When reflecting this on the LEED 4.1 assessment, the effect on LEED energy credits is less significant. Overall, through the appropriate design optimisation processes, and the consideration of the climatic context, the balance between the energy performance and health benefit for office buildings is likely to be achieved.

INTRODUCTION

The building industry has recently witnessed an increase of interest and research evidence on the implications of the built environment on occupants' health & wellbeing. The knowledge that people spend 90% of their time indoors (Klepeis et al., 2001) and that the indoor environmental quality (IEQ) can directly affect people's health and productivity (WGBC, 2014) has led to the publication of performance standards that benchmark exclusively the health-related aspects of buildings and urban environments. These include Reset (first published in 2013), the WELL Building Standard (first published in 2014) and Fitwel (first published in 2017) (Reset, 2017a; IWBI, 2014; Reset, 2017b). This has led to a debate of the effect of a "healthy building" on its operational energy use, from an environmental and sustainability point of view, which is the focus of this paper.

The selected standard to address this is the WELL Building Standard, as it has seen a fast adoption across the industry: after around 5 years' deployment, there has been 290 WELL certified projects and 3,818 registered projects across 58 countries (IWBI, 2020b). It is also aligned with other international ratings for sustainability, including LEED, BREEAM etc., and therefore often used in combination with these to pursue "healthy and sustainable buildings".

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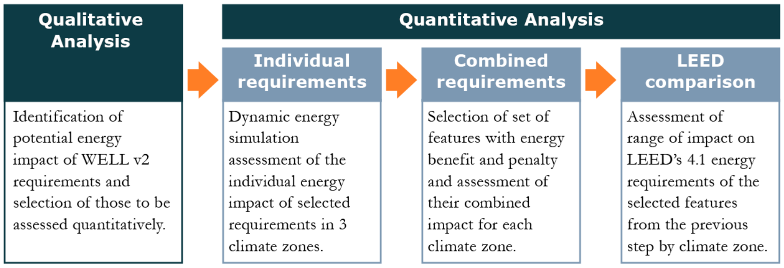
There is research reviewing and assessing the energy impact of the strategies and technologies recommended by WELL. Azerbegi (2015) conducted a qualitative review of the energy impact of WELL v1 standard. Zaatari et al. (2014) and Dai et al. (2018) also looked at the energy impact of individual strategies such as applying air filters and circadian lighting. However, to date, there is no systematic review assessing the energy impact of the whole WELL v2 Building standard, the synergies between features, and their combined effects in distinct climates.

This research aims to provide a qualitative and quantitative analysis for the WELL v2 standard (Q4 2019 edition) in terms of its energy impact exclusively on the office buildings, to help designers and engineers understand the relative impact of each WELL feature in three distinct climates, and strategically design for a better environment.

METHODOLOGY

This study provides a systematic assessment of the energy impact of WELL v2 requirements. It is divided into two main sections: qualitative analysis and quantitative analysis, as illustrated in the workflow diagram below.



Identification of potential energy impact of WELL v2 requirements and selection of those to be assessed quantitatively.

Dynamic energy simulation assessment of the individual energy impact of selected requirements in 3 climate zones.

Selection of set of features with energy benefit and penalty and assessment of their combined impact for each climate zone.

Assessment of range of impact on LEED's 4.1 energy requirements of the selected features from the previous step by climate zone.

Figure 1 Workflow diagram of the two-stage approach for this research

The assessment of the energy impact of WELL v2 follows the structure of the standard, which is organized around 10 concepts which themselves have a series of requirements organised in features and parts that provide different points.

This initial step assessed qualitatively the potential energy impact of all WELL v2 features and parts based on literature review, engineering experience and rules of thumb. These were classified into four categories: Potential energy benefit/ Potential energy penalty/ Negligible / Unknown (depending on design strategies and climate).

The quantitative analysis was done through dynamic energy modelling in three different climates. WELL features where more than one design option/scenarios are available will be individually tested and output in the result summary. 'Negligible' items are excluded in the quantitative analysis. Assumptions taken are summarised below:

Reference building. For the purpose of this research, ASHRAE 209 (2018) Medium office building was used to carry out the quantitative simulation for selected features and parts. The building geometry is shown in **Figure 2**.

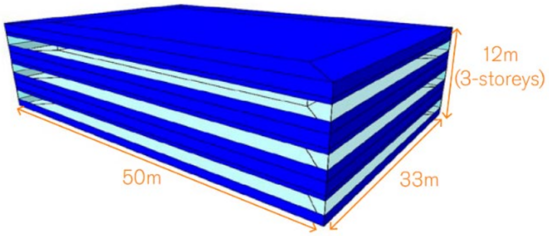


Figure 2 Medium office prototype building specified in ASHRAE 209 (2018)

Layout and design. The original ASHRAE medium office geometry was created for the whole-building level simulation, and lacked the necessary functional zoning. For the purpose of this study, bespoke layouts were created to represent typical office functions. "Base design layout" is the business-as-usual office layout design, whereas "WELL layout" is the design including a wide range of amenities and associated areas required by the WELL standard. To note, when assessing each individual feature/part, only related amenities were added to the "base design layout".

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Systems and constructions. A set of "good-practice" design assumptions were made for this research, as below:

Table 1. Systems and constructions key summary

	Base Design
Constructions	Wall U-value: 0.3 W/m²K; Floor U-value: 0.2 W/m²K; Roof U-value: 0.2 W/m²K Fenestration U-value: 2.0 W/m²K (whole system); SHGC: 0.35; VLT: 0.69
HVAC system (setpoint 20-24°C)	Fan Coil Units (FCU) + Dedicated Outdoor Air System (DOAS), direct electric resistance SHW Heating: condensing boiler (92% efficiency); Cooling: water-cooled chiller (COP=5.77)

Internal loads and profiles. Bespoke lighting layout design was carried out for this research which gave the relevant lighting power density (LPD) for each zone. Occupancy densities, small power loads, Service Hot Water (SHW) loads and outside air (OA) air rates were based on international standards such as ASHRAE 62.1 (2019).

Simulation software. IES-VE was the main software used to simulate the energy use intensity (EUI). Rhino + Grasshopper (Honeybee with Radiance) were used for the daylight simulation. DIALux was used for the artificial lighting and circadian lighting design.

Climate zones. In order to make this research applicable to as many climates/cities as possible, three cities in different ASHRAE climate zones were selected– 2A (Shenzhen), 3C (San Francisco) and 4A (London).

RESULTS AND DISCUSSION

Qualitative analysis

Across 10 WELL concepts, there are a total of 23 precondition features, further sub-divided into 59 preconditional parts. Additionally, there are a total of 97 optimisation and innovation features, which are formed by 169 optimisation parts. Those parts carry a maximum value of 202 points, from the total of 235 points, as some parts have few alternative paths to achieve the same compliance. The qualitative analysis results, summarised below, are the percentage share of each 'energy impact category' within those 59 total preconditional parts and 235 total optimisation sub-points.

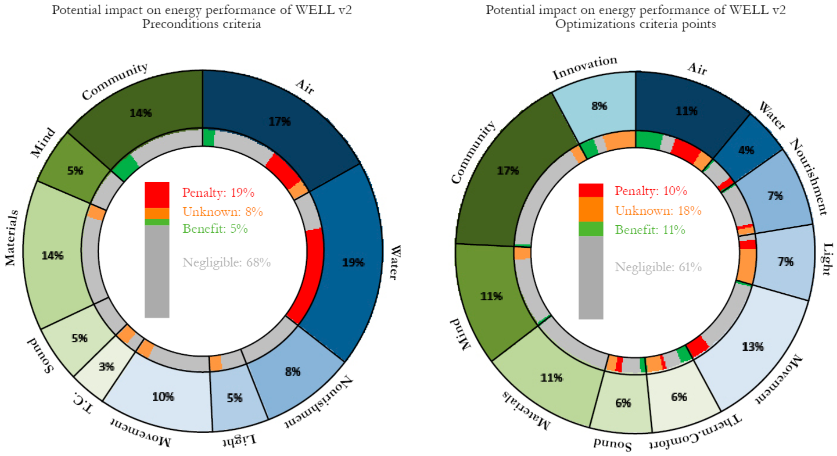

Figure 3 Qualitative analysis results summary

(References: WHO, 2010; CDC, 2018; Mondal et al., 2019; Carlesuria, 2018; Airthinx, 2020; Price Industries, 2016; Azerbegi, 2015; Global Water, 2016; IWBI, 2020a.)

As shown in the graph, most of the WELL features/parts have negligible impact on the building's operational energy. This is because most of them are related to materials, interior design, or owner's operational policies. The concepts of Air, Water, Light, and Thermal Comfort have a more direct impact on the energy performance, either positively or negatively. It is worth noting that the preconditional parts of those four concepts share 44% of total 59 preconditional parts. Therefore, depending on the strategies taken, for a building to achieve minimum WELL certification, the building's operational energy is likely to be affected to a certain extent. Regarding optimisations, those

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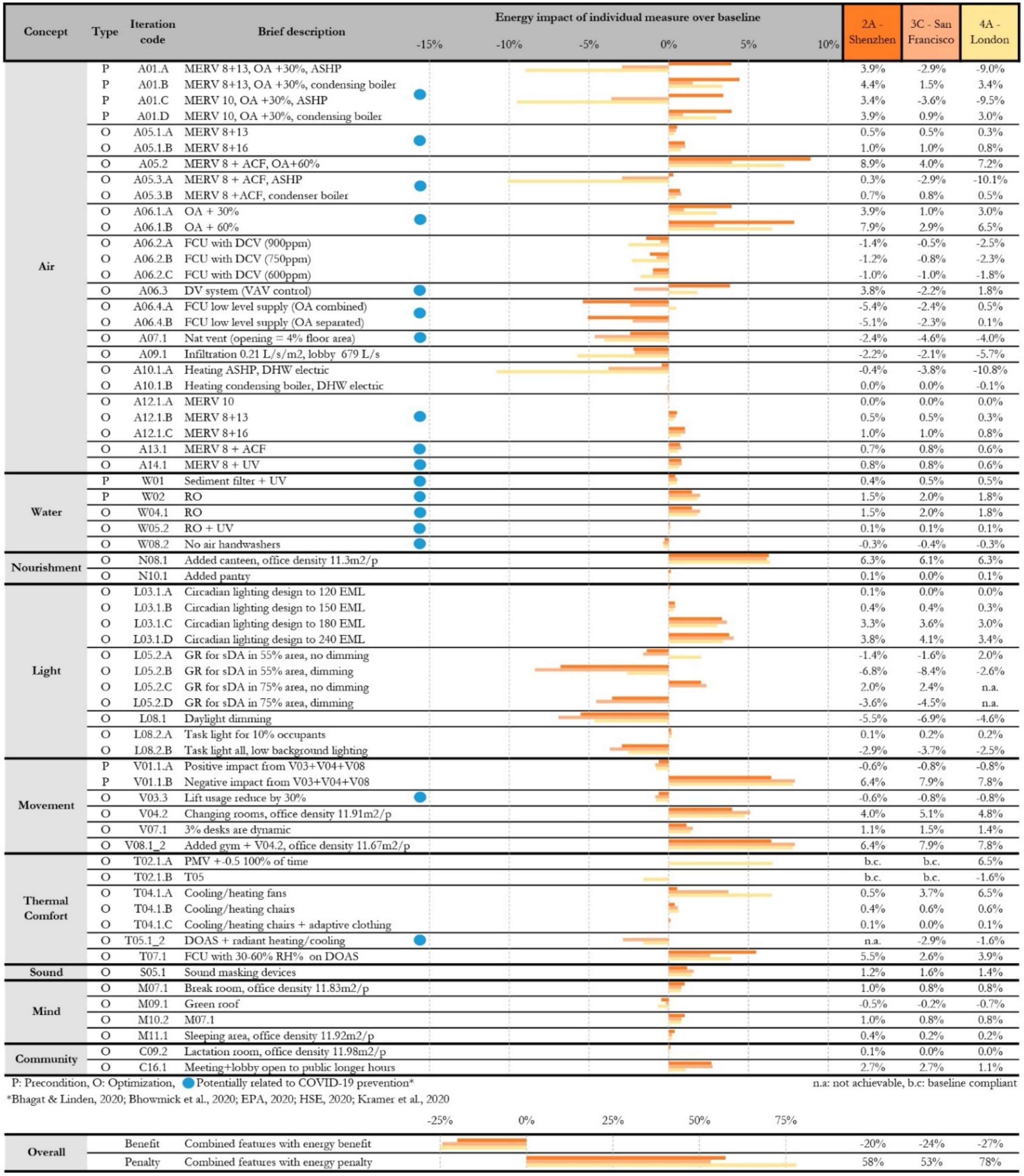
four concepts share only 29% of the total sub-points. This means once the project achieves all preconditions, depending on the design strategies and optimisations targeted, there might be no direct relationship between building's operational energy and final WELL rating levels.

Quantitative analysis

The summary of the quantitative analysis for the selected features can be found below.



Concept	Type	Iteration code	Brief description		2A - Shenzhen	3C - San Francisco	4A - London
Air	P	A01.A	MERV 8+13, OA +30%, ASHP	●	3.9%	-2.9%	-9.0%
	P	A01.B	MERV 8+13, OA +30%, condensing boiler		4.4%	1.5%	3.4%
	P	A01.C	MERV 10, OA +30%, ASHP		3.4%	-3.6%	-9.5%
	P	A01.D	MERV 10, OA +30%, condensing boiler		3.9%	0.9%	3.0%
	O	A05.1.A	MERV 8+13	●	0.5%	0.5%	0.3%
	O	A05.1.B	MERV 8+16		1.0%	1.0%	0.8%
	O	A05.2	MERV 8 + ACF, OA+60%		8.9%	4.0%	7.2%
	O	A05.3.A	MERV 8 + ACF, ASHP	●	0.3%	-2.9%	-10.1%
	O	A05.3.B	MERV 8 +ACF, condenser boiler		0.7%	0.8%	0.5%
	O	A06.1.A	OA + 30%	●	3.9%	1.0%	3.0%
	O	A06.1.B	OA + 60%		7.9%	2.9%	6.5%
	O	A06.2.A	FCU with DCV (900ppm)		-1.4%	-0.5%	-2.5%
	O	A06.2.B	FCU with DCV (750ppm)		-1.2%	-0.8%	-2.3%
	O	A06.2.C	FCU with DCV (600ppm)		-1.0%	-1.0%	-1.8%
	O	A06.3	DV system (VAV control)	●	3.8%	-2.2%	1.8%
	O	A06.4.A	FCU low level supply (OA combined)	●	-5.4%	-2.4%	0.5%
	O	A06.4.B	FCU low level supply (OA separated)		-5.1%	-2.3%	0.1%
	O	A07.1	Nat vent (opening = 4% floor area)	●	-2.4%	-4.6%	-4.0%
	O	A09.1	Infiltration 0.21 L/s/m2, lobby 679 L/s		-2.2%	-2.1%	-5.7%
	O	A10.1.A	Heating ASHP, DHW electric		-0.4%	-3.8%	-10.8%
	O	A10.1.B	Heating condensing boiler, DHW electric		0.0%	0.0%	-0.1%
	O	A12.1.A	MERV 10	●	0.0%	0.0%	0.0%
	O	A12.1.B	MERV 8+13		0.5%	0.5%	0.3%
	O	A12.1.C	MERV 8+16		1.0%	1.0%	0.8%
	O	A13.1	MERV 8 + ACF	●	0.7%	0.8%	0.6%
	O	A14.1	MERV 8 + UV	●	0.8%	0.8%	0.6%
Water	P	W01	Sediment filter + UV	●	0.4%	0.5%	0.5%
	P	W02	RO	●	1.5%	2.0%	1.8%
	O	W04.1	RO	●	1.5%	2.0%	1.8%
	O	W05.2	RO + UV	●	0.1%	0.1%	0.1%
	O	W08.2	No air handwashers	●	-0.3%	-0.4%	-0.3%
Nourishment	O	N08.1	Added canteen, office density 11.3m2/p		6.3%	6.1%	6.3%
	O	N10.1	Added pantry		0.1%	0.0%	0.1%
Light	O	L03.1.A	Circadian lighting design to 120 EML		0.1%	0.0%	0.0%
	O	L03.1.B	Circadian lighting design to 150 EML		0.4%	0.4%	0.3%
	O	L03.1.C	Circadian lighting design to 180 EML		3.3%	3.6%	3.0%
	O	L03.1.D	Circadian lighting design to 240 EML		3.8%	4.1%	3.4%
	O	L05.2.A	GR for sDA in 55% area, no dimming		-1.4%	-1.6%	2.0%
	O	L05.2.B	GR for sDA in 55% area, dimming		-6.8%	-8.4%	-2.6%
	O	L05.2.C	GR for sDA in 75% area, no dimming		2.0%	2.4%	n.a.
	O	L05.2.D	GR for sDA in 75% area, dimming		-3.6%	-4.5%	n.a.
	O	L08.1	Daylight dimming		-5.5%	-6.9%	-4.6%
	O	L08.2.A	Task light for 10% occupants		0.1%	0.2%	0.2%
	O	L08.2.B	Task light all, low background lighting		-2.9%	-3.7%	-2.5%
Movement	P	V01.1.A	Positive impact from V03+V04+V08		-0.6%	-0.8%	-0.8%
	P	V01.1.B	Negative impact from V03+V04+V08		6.4%	7.9%	7.8%
	O	V03.3	Lift usage reduce by 30%	●	-0.6%	-0.8%	-0.8%
	O	V04.2	Changing rooms, office density 11.91m2/p		4.0%	5.1%	4.8%
	O	V07.1	3% desks are dynamic		1.1%	1.5%	1.4%
	O	V08.1_2	Added gym + V04.2, office density 11.67m2/p		6.4%	7.9%	7.8%
Thermal Comfort	O	T02.1.A	PMV +-0.5 100% of time		b.c.	b.c.	6.5%
	O	T02.1.B	T05		b.c.	b.c.	-1.6%
	O	T04.1.A	Cooling/heating fans		0.5%	3.7%	6.5%
	O	T04.1.B	Cooling/heating chairs		0.4%	0.6%	0.6%
	O	T04.1.C	Cooling/heating chairs + adaptive clothing		0.1%	0.0%	0.1%
	O	T05.1_2	DOAS + radiant heating/cooling	●	n.a.	-2.9%	-1.6%
	O	T07.1	FCU with 30-60% RH% on DOAS		5.5%	2.6%	3.9%
Sound	O	S05.1	Sound masking devices		1.2%	1.6%	1.4%
Mind	O	M07.1	Break room, office density 11.83m2/p		1.0%	0.8%	0.8%
	O	M09.1	Green roof		-0.5%	-0.2%	-0.7%
	O	M10.2	M07.1		1.0%	0.8%	0.8%
	O	M11.1	Sleeping area, office density 11.92m2/p		0.4%	0.2%	0.2%
Community	O	C09.2	Lactation room, office density 11.98m2/p		0.1%	0.0%	0.0%
	O	C16.1	Meeting+lobby open to public longer hours		2.7%	2.7%	1.1%

P: Precondition, O: Optimization, ● Potentially related to COVID-19 prevention*

n.a: not achievable, b.c: baseline compliant

*Bhagat & Linden, 2020; Bhowmick et al., 2020; EPA, 2020; HSE, 2020; Kramer et al., 2020

Concept		Brief description	2A - Shenzhen	3C - San Francisco	4A - London
Overall	Benefit	Combined features with energy benefit	-20%	-24%	-27%
	Penalty	Combined features with energy penalty	58%	53%	78%

Figure 4 Quantitative analysis results summary (from IES-VE annual energy modelling)

(References: ASHRAE, 2019; Zhao et al., 2015; SCAQMD, 2019; Alpine, 2014; ASHRAE, 2016; Cho et al., 2010; Speert, 2012; Azerbegi, 2015; Complete Washroom Solutions, 2017; Office Fitness Ninjas, 2019; Acoustics Expert, 2019; SoftdB, 2019; Pasut et al., 2013; Dyson, 2020; IES, 2012.)

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In general, the quantitative analysis shows that the building's operational energy is affected by WELL features related to the following main design aspects: Fabric design, HVAC strategies, Lighting and circadian design, and the Inclusion of WELL amenity areas. Some of these, in particular those related to air and water quality, potentially have a role in preventing the spread of COVID-19 and other viruses. These topics are discussed below.

Fabric design. In WELL v2, fabric design was emphasised to cover three main topics: airtightness (air-borne pollution control), glazing ratio control (enhanced daylight) and natural ventilation (enhanced ventilation). Airtightness criteria are introduced as a part of the requirements in Feature A09. The analysis showed that 2-6% of the energy can be saved by reducing the infiltration rate from ASHRAE 90.1 baseline value (approx. 0.61 L/s/m² fabric area) to industry best practice of approx. 0.21 L/s/m² (ASHRAE, 2016; Speert, 2012), and reducing the door infiltration rate by using revolving doors/vestibules (Cho et al., 2010). This is more prominent in colder climate like London. Glazing ratio control is another important factor to consider. The base design case has a glazing ratio of 33%. For the design to achieve 1 daylight point under feature L05, in climates like Shenzhen and San Francisco, the required glazing ratio is only 25%, according to the daylight simulation. This reduced glazing ratio could bring around 1.5% energy saving potential. The benefit will be further enhanced to around 7-8% energy saving potential when this is combined with daylighting dimming control for the office spaces – one of the most energy-beneficial features in the WELL standard. However in an overcast climate such as London, or if the higher daylight threshold is pursued, the glazing ratio will need to be increased. In that case, this could cause around 2% energy penalty by changing the glazing ratio alone. It is therefore key for the façade design to find the optimal balance between the well-lit area and the perimeter energy consumption. Lastly, natural ventilation in general has a benefit on the operational energy, this is especially notable in climates like San Francisco, which can lead to around 5% annual energy saving.

HVAC design. Across the selected features in the quantitative analysis, there are 5 general air-side terminal types which were assessed in this research. They are summarised in the figure below.

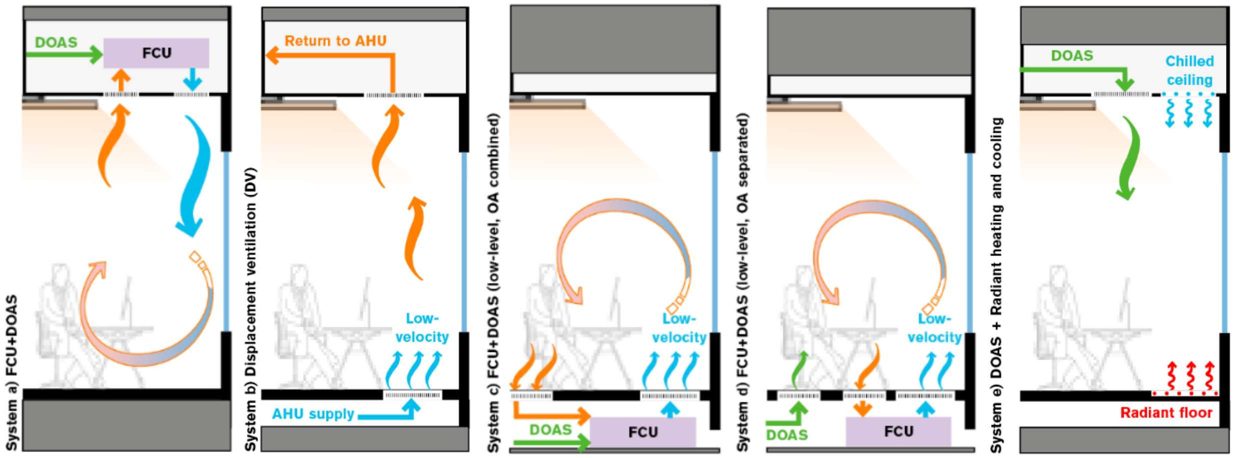

Figure 5 Types of WELL required air-side terminal strategies considered in this research

The base design uses standard overhead mixing DOAS + FCU system (system a). Feature A06 requires the conditioned air to be supplied directly into the occupied zone, through the ways of 1) displacement ventilation (system b), 2) occupied-level supply with background mechanical system (system c), or 3) occupied-level supply with separate DOAS (system d). In reality, many system types can be considered as system c or d (including displacement ventilation). However, to have a more like-for-like comparison against the base design, this research assumed similar DOAS + FCU configuration, but revised it from ceiling mounted to floor/wall mounted. Feature T05 requires radiant + DOAS system (system e) to improve the occupant radiant comfort. This was considered for San Francisco and London, but not for Shenzhen, due to its high humidity throughout the year (therefore possible condensation risk).

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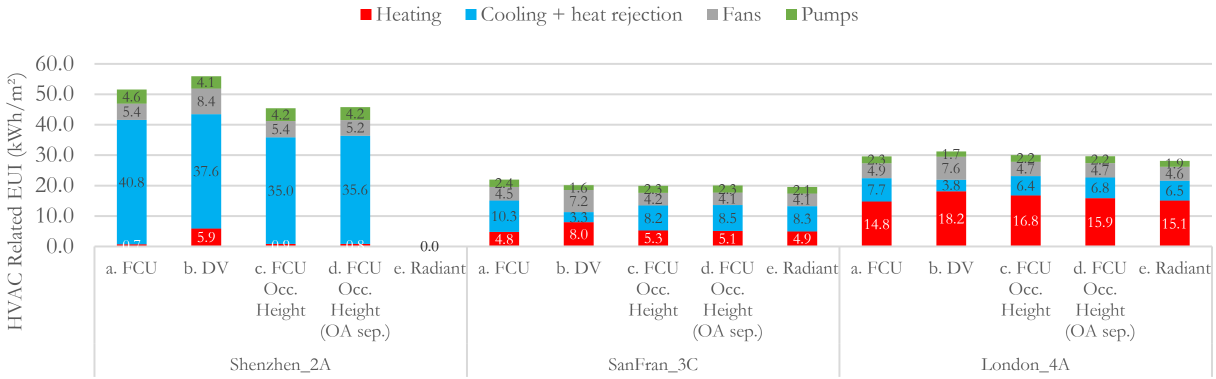

Figure 6 Comparison of EUI of different air-side terminal systems in three climates

As shown above, compared to the base case FCU system, the Displacement Ventilation (DV) system performs the best for the mild climate (San Francisco) where air-side economizer can be fully utilised, leading to 8% energy saving. However, the normal DV system uses VAV control and has rigid humidity control for the supply air, unlike the FCU type configuration (system a, c and d) which only addresses humidity control on the DOAS side. Hence when DV system is used in a more humid climate like Shenzhen or London, the dehumidification and associated reheating demand will significantly decrease the benefit of the system. In addition, as a centralised terminal type, the DV system will have higher specific fan power (SFP), which will cause around 60% fan power increase across all climates. Overall, this can make DV system perform about 6-9% worse than base FCU system in Shenzhen and London. Floor/wall mounted FCU (system c and d) utilises similar mechanism as DV system (i.e. supply the air directly to the occupied zone). However, these types of systems do not have return air path through the ceiling, therefore the 'stratified zone' is left as a free-running zone. This causes slight increases in heating energy as heat build-up in the stratified zone cannot be 'recycled' to the FCU, making it a less effective system to be used in London's (cold) climate. On the other hand, these types of systems do not require frequent dehumidification and reheating, and have much lower SFP, therefore are still beneficial in the Shenzhen climate. The radiant system (system e) currently has the best energy performance for the mild climates (San Francisco and London), mainly due to the significant fan energy saving comparing against other system types. In the suitable climate, the use of system such as radiant or DV will also help during a health crisis such as COVID-19, because they can reduce the reliance of the return air (using radiant system) or supply the air directly to the occupied height and dissipate the polluted air from the ceiling level (using DV system).

Some of the other features highlighted in **Figure 4** are also directly related to COVID-19 operations. For instance, increased OA rate will have a significant energy impact in the extreme (hot or cold) climates, resulting in 6-8% energy penalty in Shenzhen and London (with a 70% enthalpy wheel in place for the heat recovery). However, it is also observed that using demand-controlled ventilation (DCV) could help achieve 1-3% energy saving depending on the target CO_2 concentration levels. Therefore, to properly address the potential health crisis, the outdoor air plant could be sized to provide more than the minimum required OA, meanwhile it is still highly recommended to use DCV for all climates to prevent oversupplying OA during normal operation period. Or alternatively, natural ventilation can offer the increased ventilation requirements while reduce the energy consumption. The filtration system is another important design consideration in both Air and Water concepts. However, these have a minor energy impact: adding only 1-2% more annual energy consumption for the whole building. Regularly maintaining those filters is more important and possibly has a more direct energy impact.

On the water-side, the use of an air source heat pump (ASHP), especially in a cold climate such as London, seems to be one of the most effective methods to reduce energy demand (mainly because of the primary energy source switching from natural gas to electricity), which has both significant health and sustainability merits.

Lastly, regarding personal thermal comfort control (Feature T04), using electric fans will lead to much more energy

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consumption especially in the cold climates. Addressing this, through the use of heating/cooling chairs or promoting a flexible dress code, is very important for the design and management team to consider.

Lighting and circadian design. Lighting design is another key contributor to the energy consumption. Besides the automatic dimming control discussed above, there are two other key design considerations: task lighting and circadian lighting. Task lighting was requested in Feature L08: the provision can be an additional table lamp (which is a small extra plug load), or it can be achieved by introducing downlights focusing on the working surfaces, while reducing the background lighting power density from 500 to 300 lux. Simulations show that with this approach the lighting energy could be reduced by around 13%, leading to 3-4% overall energy saving in all three climates studied.

Regarding circadian lighting, it can be observed that with a minor change in lighting power density in the reception area, the baseline lighting layout can meet the 120-150EML design target. However, when targeting higher points, to achieve 180-240 EML target, the lighting power density from the LED needs to be boosted slightly to ensure adequate amount of blue light introduced to the office environment. When the design target is 240 EML, the lighting energy use is increased by 16%, causing annual energy increase of 3-4%. Note that the EML assessment was carried out based on the minimum value of all test surfaces for the worst-case scenario. If the area-weighted average can be taken so that the median value is ensured to be above the threshold (as WELL V2 verification guide suggested) (IWBI, 2020a), this could have less energy impact. In addition, other design strategies beyond the scope of this research could be explored to boost blue light for the office environment without affecting much the LPD. For instance, the luminaires could be mounted below ceiling level to be closer to the occupants (without causing glare issues). More detailed lighting design considerations and performance optimisation should be made when designing circadian lighting system.

Inclusion of the WELL amenity areas. It can be observed that when introducing WELL amenity areas, the energy use is always showing an increasing trend. This is because when amenity areas are added, this research assumes that the rest of office space maintains the same amount of employee count. Therefore, those extra added amenity loads always cause an energy increase. In addition, spaces such as gym areas will require a much higher ventilation rate and lower HVAC setpoint. Along with the changing room SHW demand, this causes a significant energy increase for a medium sized office. However, if the developer is willing to sacrifice the rentable area for those amenities, the energy penalty will be less significant (and possibly result in energy saving in some circumstances).

Combined effects. After assessing each individual feature, this study combined all the 'energy penalty' and 'energy benefit' features respectively. All preconditions are included in both cases. The results can be observed in **Figure 4**.

The 'combined energy penalty' case carries 37-38 WELL points resulting in 53-78% more annual energy use depending on the climate. While the 'combined energy benefit' case carries 13-15 WELL points and provides 20-28% energy savings in different climates.

LEED Comparison. When assessing against LEED v4.1 baseline building (ASHRAE 90.1-2016 Appendix G), the resulting impact on energy credits is less significant, as shown below.

Table 2. Performance Cost Index (PCI) calculation for ASHRAE 90.1-2016 App.G

		Proposed Building		ASHRAE Baseline		LEED
		PCI (carbon)	PCI (cost)	PCI_t (carbon)	PCI_t (cost)	(no. pts)
Shenzhen	**Base design**	0.59	0.59	0.65	0.65	2
	Combined energy benefit	0.46	0.46	0.65	0.65	9
	Combined energy penalty	0.69	0.70	0.64	0.64	0 (fail)
San Francisco	**Base design**	0.66	0.66	0.66	0.67	0 (pre-req.)
	Combined energy benefit	0.49	0.51	0.66	0.67	8
	Combined energy penalty	0.66	0.66	0.64	0.65	0 (fail)
London	**Base design**	0.58	0.55	0.67	0.68	5
	Combined energy benefit	0.43	0.45	0.68	0.68	11
	Combined energy penalty	0.68	0.61	0.67	0.67	0 (fail)

This suggests that although some WELL features might have a notably negative impact on energy, as a percentage,

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it is less significant than the actual EUI increase. While, the energy-saving strategies could still have a similar percentage of benefit on the PCIs and LEED credits. This is mainly because: 1) ASHRAE 90.1 recognises some health and wellbeing design strategies to be 'exempt' from energy penalties. For instance, when using additional air filters, the ASHRAE baseline will also address a 'pressure adjustment factor' to achieve a similar pressure drop in the baseline SFP; 2) Additional small power loads (such as gym, personal comfort devices, etc.) are considered as 'plug loads' in the ASHRAE 90.1 assessment and will be identical for the proposed and baseline buildings. This is also applicable to the occupancy density, setpoints, etc. 3) The energy benefit measures such as daylight dimming, natural ventilation or reduced infiltration are all recognised by the ASHRAE 90.1 App.G method. Therefore, when a project is designed and coordinated to achieve certain WELL feature points, it is likely that the LEED credits are not going to be significantly jeopardised. On the contrary, it might end up with more LEED v4.1 energy credits if strategies are selected as appropriate for the specific climate and context.

CONCLUSION AND FURTHER RECOMMENDATIONS

This research assessed the impact of the WELL v2 standard features on a case study office building's operational energy performance, qualitatively and quantitatively. From the qualitative analysis, most (68% of the preconditions and 61% of the optimisation points) of the WELL features have negligible energy impact, which are generally related to operational policies, interior design and materials selection. The most energy-influential features are largely related to Air, Water, Light and Thermal Comfort concepts. According to the further quantitative analysis of those energy-related features, different WELL feature requirements and associated design strategies are likely to have distinct energy impact in different climatic conditions. Each individual feature would have a relative impact that ranges between +9% (energy penalty) to -11% (energy saving), in different climates. When combining all of the 'energy penalty features' and 'energy saving features', this results in 53-78% more annual energy use and 20-28% energy saving, respectively. When compared with LEED 4.1 energy credits, using ASHRAE 90.1-2016 Appendix G method, the relative impact on the PCI are: 0-17% (carbon) and -1-19% (cost) increase, for the 'combined energy penalty case', and; 22-26% (carbon) and 20-24% (cost) saving, for 'combined energy benefit case'. This suggests that, certain health and comfort related design measures could indeed lead to more energy consumption for office buildings, however, some of those measures are also recognised by the energy assessment standard to be exempt from energy penalty. In addition, there are also some energy saving strategies related to WELL v2 which could help the project achieve better energy performance and sustainability status. Therefore, the key to the future office wellness design is to ensure responsive and appropriate design strategies are taken for the specific site location and context, while utilising effective integrated design processes at early stage involving all disciplines to better address both health and sustainability synergies and challenges.

Regarding research limitations, this study is based on a specific prototype office building only. In addition, the quantitative analysis is based on a limited number of strategies, there are many alternative compliance paths for some features, which could lead to different energy impact results. Lastly, occupant behaviour related items - which could have very significant impact on the building's overall energy consumption- were not simulated. Research addressing these issues, including other building types, design strategies and user behaviour, is recommended. Further researches on post-occupancy studies related to WELL certified buildings, including energy use, are also strongly suggested.

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