Kingspan Kooltherm®
Pipe Insulation System

The Effects of Overheating in Multi-Residential Building Corridors

Kingspan®

Contents

Executive Summary

Background

The effects of overheating in both living and working areas within a building, can lead to a detrimental impact on occupant comfort and health.

The Kingspan Kooltherm® Pipe Insulation System provides an effective solution for the insulation of pipework where there is a risk of overheating. The thermally efficient phenolic insulation core limits heat transfer and thus reduces heat gain to surrounding areas.

The Kingspan Kooltherm® Pipe Insulation System comprises premium performance Kingspan Kooltherm® Pipe Insulation, Insulated Pipe Support Inserts and FireSleeves.

The Enhanced Capital Allowance scheme for energy-saving technologies can help businesses to improve cash flow through accelerated tax relief. It encourages investment in energy-saving plant or machinery specified on the Energy Technology List (ETL) which is managed by the Carbon Trust on behalf of Government.

The ETL encourages energy saving using pipe insulation installed at an enhanced thickness above the requirements of Building Regulations and BS 5422: 2009 (Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40°C to +700°C) for hot water and heating systems.

In order to demonstrate the effectiveness of the Kingspan Kooltherm® Pipe Insulation System, Kingspan Industrial Insulation commissioned AECOM to carry out an evaluation of the relative performance of three configurations of pipe insulation when installed in the communal areas of a multi-residential building. Performance was measured against the predicted level of energy use and risk of overheating.

AECOM is a multinational engineering company providing design, consulting, construction, and management services to a wide range of clients. As one of the leading Mechanical & Electrical consultants in the UK, AECOM is familiar with each of the three types of pipe insulation options which are assessed in this report.

The results show that installing enhanced levels of Kingspan Kooltherm® Pipe Insulation to pipework in communal areas of multi-residential buildings is likely to offer a number of benefits as shown in Table 1 which can be summarised as:

- Capital cost savings of up to 26%
- Up to 32% reduction in overheating hours
- 10 year energy cost saving of up to 33%
- No additional extractor fan capital cost

	Pipe Insulation Option	% Energy Saving Offered by Kingspan Kooltherm® Enhanced Thickness of Pipe Insulation	Omitting the Effects of Additional Extract Fans		Including the Effects of Additional Extract Fans		
			10 Year Energy Cost Saving Offered by Kingspan Kooltherm® Enhanced Thickness Pipe Insulation	Additional Capital Cost to install Kingspan Kooltherm® Enhanced Thickness Pipe Insulation	10 Year Energy Cost Saving Offered by Kingspan Kooltherm® Enhanced Thickness Pipe Insulation	Additional Capital Cost to install Kingspan Kooltherm® Enhanced Thickness Pipe Insulation	% of hours with a dry resultant temperature of Greater than 28°C
A	MMMF – Minimum Standard to BS5422: 2009 installed with rubber lined clips	N/A	–	–	–	–	0.61
B	Kingspan Kooltherm® Pipe Insulation – Minimum Standard to BS5422: 2009 with Kingspan Kooltherm® Insulated Pipe Support Inserts	10.8	**£4,310**	£223 (5%)	**£4,360**	£174 (2%)	0.52
C	Kingspan Kooltherm® Pipe Insulation – ECA Specification with Kingspan Kooltherm® Insulated Pipe Support Inserts	31.5	**£12,520**	£694 (16%)	**£13,840**	–£1,623 (–26%)	0.41

Table 1: A summary of the results found in AECOM's report

Introduction

Recent years have seen increasing occurrences of record high temperatures, heat waves and hot periods documented, not just for the UK, but globally.

With this continued rise in average temperatures, combined with highly insulated buildings, it is clear that overheating in our living and working spaces is quickly becoming a global concern not only for its detrimental impact on occupant comfort but for the negative effect on heating and cooling energy use.

Reasons to mitigate the risk of overheating in buildings extend beyond comfort and wasted energy. A comfortable indoor temperature is vital to ensuring our general well-being and exposure to prolonged or excessively high temperatures poses a real risk to occupant health.

An internal temperature of 25°C during occupied hours has traditionally been used as a benchmark for thermal comfort with a preferred maximum temperature of 28°C.

A building that can passively reduce the risk of overheating is less likely to require the installation, operation, maintenance and the associated costs of active systems to keep them cool.

Therefore, a building that reduces its risk of overheating by the application of an enhanced level of Kingspan Kooltherm® Pipe Insulation, rather than just insulating to BS 5422: 2009 (Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40°C to +700°C) will cost less to run, require less maintenance and be more comfortable and attractive to occupiers and purchasers.

The 'CIBSE Heat networks: Code of Practice for the UK' recommends enhanced thicknesses of phenolic insulation and the use of insulated pipe support inserts to improve system efficiency and reduce the potential for overheating in buildings with heat networks.

In addition, the Building Research Establishment's Environmental Assessment Method (BREEAM) awards Health and Well-being credits to buildings that maintain a thermally comfortable environment for occupants. Kingspan Kooltherm® Pipe Insulation can contribute to 3 credits within HEA04 Thermal Comfort, from the design and thermal modelling stages through to adaptability to climate change.

Kingspan Kooltherm® Pipe Insulation also has Eurofins Indoor Air Comfort Gold certification, which highlights products which have best-in-class low emissions, thus good for indoor air quality.

Enhanced Capital Allowances

The Enhanced Capital Allowances scheme (ECA) brings forward tax relief, so that investment costs can be set against profits in an earlier period than would otherwise be the case and thus give a cash-flow boost in the year in which the investment is made.

The ECA Scheme enables businesses to write-off the whole cost of an investment in energy saving equipment against their taxable profits for the period during which they make the investment (typically within the same year for small investments).

Qualifying technologies and products are specified in the Energy Technology List, all pipe insulation installed in commercial and industrial buildings, or on process pipework, is eligible for the ECA Scheme.

Kingspan Kooltherm® Pipe Insulation is eligible for the Enhanced Capital Allowance Scheme.

In July 2013, the ECA Energy Technology List was updated to further encourage energy saving, with new performance targets over and above the requirements of the Building Regulations and BS 5422: 2009 (Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40°C to +700°C) for hot water and heating systems.

The Energy Technology List states performance requirements for pipe insulation as maximum heat gain for cold pipework and maximum heat loss for hot pipework.

Example of required thicknesses

Kingspan Kooltherm® Pipe Insulation's low thermal conductivity allows the specified thermal performance to be achieved with up to 57% thinner insulation compared with Man Made Mineral Fibre (MMMF). The thicknesses shown in Figure 1 are for a 25mm Nominal Bore (NB) / 33.7mm Outer Diameter (OD) pipe operating at +75°C in an ambient temperature of +15°C.

Kingspan Kooltherm® Pipe Insulation ECA thicknesses can be installed in place of BS 5422: 2009 compliant MMMF insulation, reducing heat loss of the system, without increasing pipe spacing. Figure 2 shows that the increased thicknesses of MMMF insulation required for ECA compliance on hot water and low temperature heating water (LTHW) cannot be installed without significantly increasing the spacing between pipes.

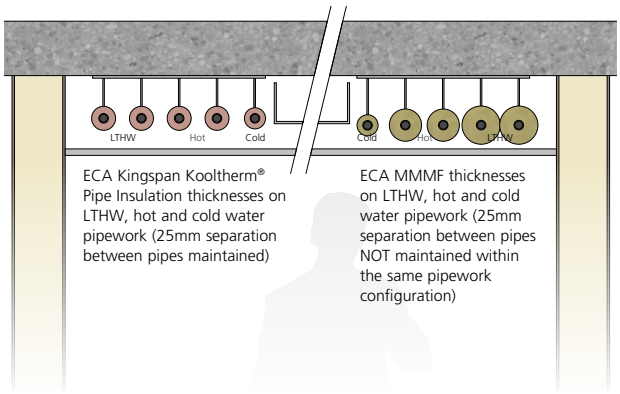

Figure 2: Sufficient space for insulation is required

Thickness: Complies with:	20mm Kingspan Kooltherm® Pipe Insulation	35mm MMMF	25mm Kingspan Kooltherm® Pipe Insulation	50mm MMMF
BS 5422 : 2009 Max. heat loss 11.07 W/m	✳	✳	✳	✳
ECA Tax break + energy saving Max. heat loss 9.86 W/m	✳	✳	✳	✳
Saves space whilst saving energy	✳	✳	✳	✳

Figure 1: Insulation thickness comparison

Further information can be found in the Kingspan Technical Bulletin for Enhanced Capital Allowances, available to download from www.kingspaninsulation.co.uk

Analysis

Current Practice

- Building services and HVAC systems are a common feature of new build and refurbishment construction works;
- Mild steel, stainless steel, carbon steel, copper and plastic pipework is typically used for HVAC and building services pipework, which is then insulated;
- The insulating material is often not considered until late in a projects design process;
- Those who are not intimate with the projects constraints, may be responsible for selecting the pipe insulation material;
- Services design co-ordination commonly occurs concurrently with construction; and
- There is a risk that little or no attention is paid to the operating and running cost of the pipework system with respect to insulation choice.

Assessing the Alternatives

The aim of this report is to quantify the energy and financial cost benefits that result from insulating the pipework of non–domestic buildings using an enhanced thickness of Kingspan Kooltherm® Pipe Insulation.

The client's specification for pipework is normally limited to a set of performance criteria rather than a specific insulation material. The actual selection of the pipework insulation material is usually made by the mechanical services contractor who may not be aware of the economic and energy performance implications of the pipework insulation that is installed.

The selection of HVAC and building services pipework insulation can have a significant impact on user comfort, health and wellbeing, running costs and carbon emissions. If not specified correctly, extract fans may be required to cool an overheated building which can increase energy use and running costs.

Enhanced thicknesses of Kingspan Kooltherm® Pipe Insulation reduce capital and running costs when compared with standard thicknesses of MMMF, whilst, at the same time, offering additional advantages to the specifying consultant, the M&E contractor, the insulation contractor, the facilities manager, the property developer and the building owner.

Review of the Alternatives

Kingspan Industrial Insulation Ltd commissioned AECOM to investigate the effects of specifying enhanced pipe insulation thickness, on comfort, cost and carbon emissions in multi-residential buildings.

The following section is a summary of the economic and energy performances calculated for the three pipework insulation options assessed.

AECOM carried out the evaluation using IES dynamic thermal modelling, which is an integrated suite of applications based around one 3D geometrical model. The three insulation systems evaluated were:

- **Option A:** Man Made Mineral Fibre (MMMF) minimum standard with rubber bracket insert
- **Option B:** Kingspan Kooltherm® Pipe Insulation minimum standard with a Kingspan Kooltherm® Insulated Pipe Support Insert
- **Option C:** An enhanced thickness of Kingspan Kooltherm® Pipe Insulation with a Kingspan Kooltherm® Insulated Pipe Support Insert

As Options A and B result in greater losses of heat from pipework into the building compared to Option C, the analysis includes the installation of additional extract fans to dissipate this additional heat. The analysis also includes an estimate of the additional capital cost of the fans and the costs of the energy they would consume. Where relevant the following tables show the results both with and without the effects of the additional extract fans.

The case-study building used for the analysis was based on a project for which AECOM recently completed the mechanical and electrical design, as well as providing sustainability advice services. Further details can be found in Appendix 1.

Annual Energy Requirement and Carbon Dioxide Emissions

AECOM compared the annual energy requirement for each of the three pipe insulation options. The results in Table 2 show that using a standard thickness to BS 5422: 2009 (Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40°C to +700°C) of Kingspan Kooltherm® Pipe Insulation, a 10.8% saving can be achieved however using an enhanced thickness of Kingspan Kooltherm® Pipe Insulation can provide 31.5% energy saving.

Pipe Insulation Option		Annual Energy Requirement of Modelled LTHW and DHW Pipework (MWh)	Annual Carbon Dioxide Emissions from Modelled LTHW and DHW Pipework ($kgCO_2$)	% Energy Saving Offered by Kingspan Kooltherm® Enhanced Thickness of Pipe Insulation
A	MMMF - Minimum Standard to BS5422: 2009 installed with rubber lined clips	107.8	23,283	N/A
B	Kingspan Kooltherm® Pipe Insulation – Minimum Standard to BS5422: 2009 with Kingspan Kooltherm® Insulated Pipe Support Inserts	96.1	20,760	10.8
C	Kingspan Kooltherm® Pipe Insulation – ECA Specification with Kingspan Kooltherm® Insulated Pipe Support Inserts	73.8	15,946	31.5

Table 2: Annual Energy Requirement and Carbon Dioxide Emissions as a result of Pipework Heat Losses

Notes:

The annual energy requirement for each option is calculated as the gas consumed by the boilers to offset the pipework heat losses. This, therefore, accounts for the efficiency of the boilers in the case study building, which are assumed to be 95% efficient.

Based on the government carbon emissions factor (cef) for natural gas of 0.216kgCO_2/kWh, the above carbon dioxide emissions were calculated to result from the heat loss from the pipework.

Analysis

Annual Energy Costs

AECOM compared the energy costs changes as a result of heat loss from the pipework, associated with the three pipe insulation options. Table 3 shows that enhanced thicknesses of Kingspan Kooltherm® Pipe Insulation can reduce energy consumption by up to 28%*, when compared with standard BS 5422: 2009 (Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40°C to +700°C) insulation thicknesses, offering a faster payback and a lifetime of operational energy savings.

But it's not just about the money. The enhanced performance of Kingspan Kooltherm® Pipe Insulation not only makes sound financial sense, it can help to prevent overheated buildings, and create enhanced occupier and user thermal comfort.

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	Pipe Insulation Option	Omitting the Effects of Additional Extract Fans			Including the Effects of Additional Extract Fans		
		Annual Energy Cost for Modelled LTHW and DHW Pipework	Annual Energy Cost Saving Offered by Kingspan Kooltherm® Enhanced Thickness Pipe Insulation	10 Year Energy Cost Saving Offered by Kingspan Kooltherm® Enhanced Thickness Pipe Insulation	Annual Energy Cost for Modelled LTHW and DHW Pipework	Annual Energy Cost Saving Offered by Kingspan Kooltherm® Enhanced Thickness Pipe Insulation	10 Year Energy Cost Saving Offered by Kingspan Kooltherm® Enhanced Thickness Pipe Insulation
A	MMMF – Minimum Standard to BS5422: 2009 installed with rubber lined clips	£3,973	–	–	£4,105	–	–
B	Kingspan Kooltherm® Pipe Insulation – Minimum Standard to BS5422: 2009 with Kingspan Kooltherm® Insulated Pipe Support Inserts	£3,542	£431	£4,310	£3,642	£463	£4,630
C	Kingspan Kooltherm® Pipe Insulation – ECA Specification with Kingspan Kooltherm® Insulated Pipe Support Inserts	£2,721	£1,252	£12,520	£2,721	£1,384	£13,840

Table 3: Annual energy cost changes as a result of pipework heat losses

Note:

Based on the energy prices of 11.830p/kWh and 3.685p/kWh for electricity and gas respectively.

Capital Cost

AECOM also calculated the approximate capital costs for the three pipe insulation options considered, using Kingspan Industrial Insulation data retrieved from the industry market place at the time of the analysis. It can be seen in Table 4 that although the initial capital cost of Options B and C were more than Option A, the additional cost is quickly recovered through reduced operational energy demand.

Options A and B result in greater losses of heat from pipework into the building; therefore the analysis includes the installation of additional extract fans to dissipate this additional heat. The analysis includes an estimate of the additional capital cost of these fans and the costs of the energy they would consume. When the additional cost of installing extract fans is included then Option C becomes the cheapest option, being £1,623 cheaper than Option A.

These results show that a 26% capital cost saving can be achieved by installing an enhanced thickness of Kingspan Kooltherm® Pipe Insulation when compared with the minimum standard of MMMF.

Pipe Insulation Option		Omitting the Effects of Additional Extract Fans		Including the Effects of Additional Extract Fans	
		Capital Cost of Pipe Insulation for Modelled LTHW and DHW Pipework (£)	Additional Capital Cost to install Kingspan Kooltherm® Enhanced Thickness Pipe Insulation	Capital Cost of Pipe Insulation for Modelled LTHW and DHW Pipework and Extract Fans (£)	Additional Capital Cost to install Kingspan Kooltherm® Enhanced Thickness Pipe Insulation
A	MMMF - Minimum Standard to BS5422: 2009 installed with rubber lined clips	£4,221	–	£6,363	–
B	Kingspan Kooltherm® Pipe Insulation – Minimum Standard to BS5422: 2009 with Kingspan Kooltherm® Insulated Pipe Support Inserts	£4,443	£223 (5%)	£6,537	£174 (2%)
C	Kingspan Kooltherm® Pipe Insulation – ECA Specification with Kingspan Kooltherm® Insulated Pipe Support Inserts	£4,914	£694 (16%)	£4,914	-£1,623 (-26%)

Table 4: Capital costs of each pipe insulation option

**ECA Specification Guide*

Analysis

Simple Payback Period

Given the annual energy cost savings and the capital costs, the simple payback periods of the various options have been calculated. Table 5 shows the simple payback periods for switching between the 3 insulation options both with and without the effects of the additional extract fans. When the extract fans are taking into consideration, Kingspan Kooltherm® Pipe Insulation installed to ECA Specification with Kingspan Kooltherm® Insulated Pipe Support Inserts is the cheapest of the three options, and has an immediate payback.

Pipe Insulation Option	Simple payback period excluding the cost impacts of installing and running additional extract fans (yrs)	Simple payback period including the cost impacts of installing and running additional extract fans (yrs)
Kingspan Kooltherm® Pipe Insulation – Minimum Standard to BS5422: 2009 with Kingspan Kooltherm® Insulated Pipe Support Inserts **compared with** MMMF - Minimum Standard to BS5422: 2009 installed with rubber lined clips	0.52	0.38
Kingspan Kooltherm® Pipe Insulation – ECA Specification with Kingspan Kooltherm® Insulated Pipe Support Inserts **compared with** MMMF - Minimum Standard to BS5422: 2009 installed with rubber lined clips	0.55	Immediate
Kingspan Kooltherm® Pipe Insulation – ECA Specification with Kooltherm® Insulated Pipe Support Inserts **compared with** Kingspan Kooltherm® Pipe Insulation – Minimum Standard to BS5422: 2009 with Kingspan Kooltherm® Insulated Pipe Support Inserts	0.57	Immediate

Table 5: Simple payback periods for switching between the three options considered

Thermal Comfort

The thermal comfort performance of the occupied spaces within the case study building, have been assessed by evaluating the number of hours each space experiences temperatures of over 25ºC and 28ºC. CIBSE Guide A recommends 25°C as an acceptable summer indoor design operative temperature (for non-air conditioned office buildings) and recommends limiting the expected occurrence of operative temperatures above 28ºC to 1% of the annual occupied period. Between 25ºC and 28ºC, occupants may feel hot, uncomfortable and show lower productivity. Indoor operative temperatures that stay at or over 28°C for long periods of the day will, except during prolonged hot spells, result in dissatisfaction for many occupants.

The risk of overheating can be mitigated by the use of mechanical cooling or additional ventilation (either natural or mechanical); for the purposes of this study the preferred approach was to introduce additional extract ventilation to the affected spaces.

Table 6 shows that insulation options A and B result in greater losses of heat from pipework compared to Option C and as a result require additional extract ventilation. An enhanced thickness of Kingspan Kooltherm® Pipe Insulation can provide up to 32% reduction in overheating hours at a room temperature greater than 28°C and a reduction of up to 25% at a room temperature greater than 25°C.

It can be seen in the tables in Appendix 2, that Option C offers the best thermal comfort performance for the communal occupied areas of the building and in particular that WCs and the laundry areas are at greater risk of overheating simply due to the amount of pipework in these relatively small spaces. In some cases, many of the rooms, insulated with Option A would have experienced more than an additional 100 hours at temperatures above 28ºC when compared to Option C.

Options A and B provided reduced thermal comfort levels, due to the higher resultant heat gains. In order for Options A and B to provide similar thermal comfort levels to Option C, it was found that mitigation could be achieved by using increased ventilation. Wall mounted extract fans were chosen, as they would draw hot air from the overheated spaces and would therefore help to offset the higher pipework heat gains.

The addition of the extract fans had an implication on the cost of extra energy use and additional capital cost of the fans themselves. See Appendix 3.

	% of hours with a dry resultant temperature of Greater than 25°C			% of hours with a dry resultant temperature of Greater than 28°C		
	A	B	C	A	B	C
Average	8.85	8.03	6.63	0.61	0.52	0.41

Table 6: Percentage of hours with a dry resultant temperature

Conclusion

The research shows that, increasing the performance of the insulation provided to pipework within the communal areas of a multi-residential building, has a beneficial impact on thermal comfort, heat loss and energy use. It is found that, although it is possible to bring the performance of the options with a lower insulation specification in line with the option utilising an enhanced level of insulation, a significant amount of additional extract ventilation is required. It is found for example that for the MMMF standard insulation option, an additional 405 l/s of extract ventilation is required to the communal areas, which is provided by a combination of new extract fans and increasing the flow rates provided by the existing extract fans. In order to bring the thermal comfort performance of Option A (MMMF) in line with the Kingspan Kooltherm® Pipe Insulation enhanced thickness, Option C, it has been calculated that an additional energy cost of £132.35 per year would be incurred to run the extract fans.

The report also highlights that enhanced insulation specifications can be achieved at the estimated additional capital cost of £222 for the minimum Kingspan Kooltherm® Pipe Insulation, Option B and £693 for Option C. However, when the additional cost of installing extract fans is included then Option C becomes the cheapest option, at £1,623 less than Option A.

Similarly, the simple payback periods are dependent on whether the effects of these additional extract fans are included. In the various scenarios considered, the simple payback periods of improving the pipe insulation is calculated as ranging from immediate (in situations where the capital cost was reduced) up to 0.57 years.

The reduction in carbon dioxide emissions resulting from pipework heat losses has been calculated to be 10.8% when changing from Option A to Option B and 31.5% when changing from Option A to Option C.

In summary, based on the research undertaken by AECOM, a number of benefits have been identified when improving the thickness of insulation on heating and hot water pipework:

Changing from Option A to Option B:

- 10.8% reduction in heat loss and associated carbon dioxide emissions
- Annual energy cost saving of £431 when excluding the effects of additional extract fans
- Annual energy cost saving of £463 when including the effects of additional extract fans
- 10 year energy cost saving of £4,310 when excluding the effects of additional extract fans
- 10 year energy cost saving of £4,630 when including the effects of additional extract fans
- 5% reduction in capital cost of pipe insulation when excluding the effects of additional extract fans
- Simple payback period of 0.38 years when excluding the effects of additional extract fans
- Simple payback period of 0.52 years when including the effects of additional extract fans

Changing from Option A to Option C:

- 31.5% reduction in heat loss and associated carbon dioxide emissions
- Annual energy cost saving of £1,252 when excluding the effects of additional extract fans
- Annual energy cost saving of £1,384 when including the effects of additional extract fans
- 10 year energy cost saving of £12,520 when excluding the effects of additional extract fans
- 10 year energy cost saving of £13,840 when including the effects of additional extract fans
- 16% reduction in capital cost of pipe insulation when excluding the effects of additional extract fans
- Immediate payback when excluding the effects of additional extract fans
- Simple payback period of 0.57 years when including the effects of additional extract fans

Appendices

Appendix 1

Case Study Building

The case-study building is a multi-unit residential extra care building, comprising 59 self-contained apartments distributed over 3 floors with a bistro, served by a catering kitchen and a central lounge available to all residents. Ancillary staff spaces are also provided, along with laundries and other residents' facilities. The building has a communal heating system, with two Constant Temperature (CT) Low Temperature Hot Water (LTHW) heating circuits, one serving the non-residential spaces, including the residents' lounges and staff rooms, and the other serving the Heat Interface Units (HIU) in the apartments. The HIU's provide heating and domestic hot water to the apartments, and therefore in order to meet demands at any time of the day or night, the residential CT circuit, running within the common circulation areas, constantly has hot water circulating through it.

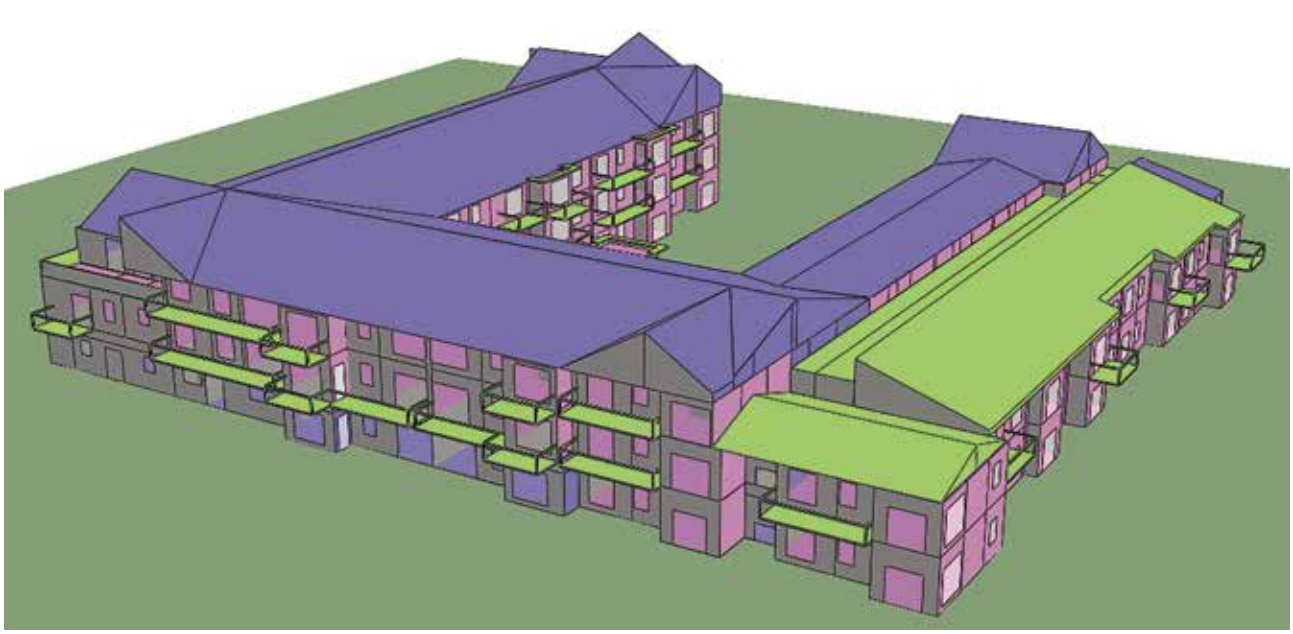

Figure 3: IES Dynamic thermal model used for the report

Appendices

Appendix 2

The results of the thermal comfort assessment before any mitigation measures have been implemented.

	Number of hours with a dry resultant temperature of greater than 25°C			Number of hours with a dry resultant temperature of greater than 28°C		
	A	B	C	A	B	C
00_Circulation_01	971	799	560	11	8	3
00_Circulation_02	718	613	486	0	0	0
00_Circulation_02a	628	535	375	3	0	0
00 Circulation_03	703	582	404	10	9	4
00 Circulation_04	1085	953	686	0	0	0
00_Circulation_05	1007	822	660	0	0	0
00_Circulation_06	490	462	389	0	0	0
00_Dining_Common	2439	2347	2249	0	0	0
00_Kitchen_common_01	378	367	354	84	82	80
00_Laundry_01	499	490	479	104	100	95
00_Lobby	413	407	405	29	29	29
00_Lounge_Common	831	759	672	0	0	0
00_Office_01	526	518	512	57	57	55
00_Office_02	242	238	231	23	23	23
00_Office_Manager	253	250	248	28	28	28
00_R&R_01	363	316	279	3	3	2
00_R&R_02	377	353	317	19	17	15
00_Stairs_01	158	153	144	13	13	13
00_Stairs_02	235	234	231	25	24	24
00_stairs_03	109	108	104	11	11	10
00_WC_Common_01	1692	1592	1511	435	380	310
00_WC_Common_02	1463	1368	1248	196	166	123
00_WC_Common_03	1222	1161	1093	143	124	100
01_Circulation_01	1656	1409	916	56	42	11
01_Circulation_02	1211	983	629	70	45	22
01_Circulation_02_a	1374	1060	694	49	33	8
01_Circulation_03	1840	1545	1013	145	92	46
01_Circulation_04	1566	1505	1172	0	0	0
01_Circulation_06	772	643	454	28	19	12
01_Laundry_01	527	495	476	100	89	80
01_R&R_01	325	285	248	11	11	10
01_R&R_02	360	321	267	3	2	2
01_StaffRest	254	236	201	12	12	11
01_Stairs_01	162	161	152	13	15	13
01_Stairs_02	229	228	226	26	26	26
01_Stairs_03	120	116	114	15	14	13
01_Unit1	382	362	343	0	0	0
01_Unit2	464	444	417	0	0	0
01_WC_Common_02	1727	1603	1435	319	239	164
01_WC_Common_03	1249	1174	1092	140	112	88
02_Circulation_01	596	534	358	23	19	13
02_Circulation_02	1571	1404	884	38	30	19
02_Circulation_02_a	1201	994	566	23	20	15
02_Circulation_03	976	808	472	31	26	21
02_Circulation_04	917	747	507	32	24	22
02_Circulation_05	1578	1567	1360	0	0	0
02_Laundry_01	452	446	436	96	92	85
02_Lounge_Common	523	518	508	65	64	60
02_R&R_01	534	489	431	6	6	6
02_R&R_02	145	134	118	1	1	0
02_Stairs_01	225	223	220	26	26	26
02_Stairs_02	178	204	185	12	15	13
02_Stairs_03	140	132	124	16	16	15
02_WC_Common_02	1426	1346	1221	218	184	154
02_WC_Common_03	1146	1124	1071	152	138	116

Table 7: Summary of thermal comfort performance for occupied rooms for the three insulation options assessed (number of hours)

	% of hours with a dry resultant temperature of greater than 25°C			% of hours with a dry resultant temperature of greater than 28°C		
	A	B	C	A	B	C
00_Circulation_01	11.08	9.12	6.39	0.13	0.09	0.03
00_Circulation_02	8.20	7.00	5.55	0.00	0.00	0.00
00_Circulation_02_a	7.17	6.11	4.28	0.03	0.00	0.00
00_Circulation_03	8.03	6.64	4.61	0.11	0.10	0.05
00_Circulation_04	12.39	10.88	7.83	0.00	0.00	0.00
00_Circulation_05	11.50	9.38	7.53	0.00	0.00	0.00
00_Circulation_06	5.59	5.27	4.44	0.00	0.00	0.00
00_Dining_Common	27.84	26.79	25.67	0.00	0.00	0.00
00_Kitchen_common_01	4.32	4.19	4.04	0.96	0.94	0.91
00_Laundry_01	5.70	5.59	5.47	1.19	1.14	1.08
00_Lobby	4.71	4.65	4.62	0.33	0.33	0.33
00_Lounge_Common	9.49	8.66	7.67	0.00	0.00	0.00
00_Office_01	6.00	5.91	5.84	0.65	0.65	0.63
00_Office_02	2.76	2.72	2.64	0.26	0.26	0.26
00_Office_Manager	2.89	2.85	2.83	0.32	0.32	0.32
00_R&R_01	4.14	3.61	3.18	0.03	0.03	0.02
00_R&R_02	4.30	4.03	3.62	0.22	0.19	0.17
00_Stairs_01	1.80	1.75	1.64	0.15	0.15	0.15
00_Stairs_02	2.68	2.67	2.64	0.29	0.27	0.27
00_stairs_03	1.24	1.23	1.19	0.13	0.13	0.11
00_WC_Common_01	19.32	18.17	17.25	4.97	4.34	3.54
00_WC_Common_02	16.70	15.62	14.25	2.24	1.89	1.40
00_WC_Common_03	13.95	13.25	12.48	1.63	1.42	1.14
01_Circulation_01	18.90	16.08	10.46	0.64	0.48	0.13
01_Circulation_02	13.82	11.22	7.18	0.80	0.51	0.25
01_Circulation_02_a	15.68	12.10	7.92	0.56	0.38	0.09
01_Circulation_03	21.00	17.64	11.56	1.66	1.05	0.53
01_Circulation_04	17.88	17.18	13.38	0.00	0.00	0.00
01_Circulation_06	8.81	7.34	5.18	0.32	0.22	0.14
01_Laundry_01	6.02	5.65	5.43	1.14	1.02	0.91
01_R&R_01	3.71	3.25	2.83	0.13	0.13	0.11
01_R&R_02	4.11	3.66	3.05	0.03	0.02	0.02
01_StaffRest	2.90	2.69	2.29	0.14	0.14	0.13
01_Stairs_01	1.85	1.84	1.74	0.15	0.17	0.15
01_Stairs_02	2.61	2.60	2.58	0.30	0.30	0.30
01_Stairs_03	1.37	1.32	1.30	0.17	0.16	0.15
01_Unit1	4.36	4.13	3.92	0.00	0.00	0.00
01_Unit2	5.30	5.07	4.76	0.00	0.00	0.00
01_WC_Common_02	19.71	18.30	16.38	3.64	2.73	1.87
01_WC_Common_03	14.26	13.40	12.47	1.60	1.28	1.00
02_Circulation_01	6.80	6.10	4.09	0.26	0.22	0.15
02_Circulation_02	17.93	16.03	10.09	0.43	0.34	0.22
02_Circulation_02_a	13.71	11.35	6.46	0.26	0.23	0.17
02_Circulation_03	11.14	9.22	5.39	0.35	0.30	0.24
02_Circulation_04	10.47	8.53	5.79	0.37	0.27	0.25
02_Circulation_05	18.01	17.89	15.53	0.00	0.00	0.00
02_Laundry_01	5.16	5.09	4.98	1.10	1.05	0.97
02_Lounge_Common	5.97	5.91	5.80	0.74	0.73	0.68
02_R&R_01	6.10	5.58	4.92	0.07	0.07	0.07
02_R&R_02	1.66	1.53	1.35	0.01	0.01	0.00
02_Stairs_01	2.57	2.55	2.51	0.30	0.30	0.30
02_Stairs_02	2.03	2.33	2.11	0.14	0.17	0.15
02_Stairs_03	1.60	1.51	1.42	0.18	0.18	0.17
02_WC_Common_02	16.28	15.37	13.94	2.49	2.10	1.76
02_WC_Common_03	13.08	12.83	12.23	1.74	1.58	1.32

Table 8: Summary of thermal comfort performance for occupied rooms for the three insulation options assessed (percentage of hours)

Appendices

Appendix 3

Total extract flow, additional energy use and costs and additional capital cost of implementing extract fans to mitigate overheating.

	Total Peak Extract Flow Rate Added to Mitigate Thermal Comfort (l/s)	Annual Extra Energy Use by Extract Fans (kWh)	Cost of Extra Energy to Run Extract Fans (£)
Option A	405	1118.78	132.35
Option B	315	845.03	99.97
Option C	N/A	N/A	N/A

Table 9: Summary of extract ventilation required to mitigate effects of higher pipework heat gains

	Additional Capital Cost of Extract Fans to Mitigate Overheating (£)
Option A	£2,143
Option B	£2,094
Option C	N/A

Table 10: Additional capital costs involved with providing extract ventilation to enhance thermal comfort performance

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