Infrared Heating - The Experience of 20 UK Households

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In terms of domestic heating, the UK faces a major challenge from the combination of fossil fuel reduction, the rising cost of energy and our poorly insulated housing stock. We need to find ways to keep people comfortably and affordably warm in a diversity of housing without wasting energy.

Infrared (IR) heating is one option. Instead of heating the air, IR panels heat the occupants directly along with the thermal mass of the room (walls, ceiling, floor and furniture). This mass absorbs the heat and radiates back into the room which gradually warms the entire space.

Given that IR heating is decentralised and heats people directly, what difference does that make to people's thermal comfort and their home's energy efficiency?

To address this question, 20 households with IR as their primary source of heating were interviewed. They varied in the type of housing, insulation levels and number of occupants. The interviews covered why they chose IR heating, how they operate it, what they see as the main advantages and disadvantages, their thermal comfort, energy consumption and thoughts on cost.

Summary of findings

The choice of a new heating system was triggered either by moving to a new home or renovating an existing one. 12 households considered a heat pump but rejected it either because of: installation cost, not wanting either a centralised or wet system with pipes or because their property was perceived as a poor match for this form of heating.

The households were all delighted with and enthusiastic about their IR heating[2]. Only 2 households kept the heating on 24/7. 12 households operated some time scheduling together with ad hoc, 'in the moment', adjustments. 6 households didn't bother with any scheduling preferring to turn IR panels on & off in rooms just when they needed them or when they felt chilly.

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[2] With the exception of one householder who was having trouble achieving the heat she wanted. This problem has apparently now been resolved.

The households saw the main advantages of IR heating as quick, flexible control of their thermal comfort, if and when they needed it. They loved the sensation of sun-like heat directly on their bodies as well as the enveloping warmth. They also appreciated the option of ceiling panels - both for sitting under feeling the warmth and for the freeing of wall space.

The perceived disadvantages were primarily user interface issues with the mobile app and struggles and confusion over thermostat control. The app issues do not appear to be related to the IR technology itself.

The confusion over control by thermostats may be due to the fact that IR heaters work by emitting a high proportion of heat energy via electromagnetic waves that travel through the air and are transformed into heat only when they are absorbed and warmed by a body or object exposed to them. This means that, unlike traditional space heating which primarily heats the entire volume of air in a room, thermostat controls which operate on room temperature can be misleading in the case of IR. This can create a disconnect between how warm someone feels and the thermostat reading for the room. IR effectively highlights the fact individual thermal comfort is not the equivalent to the exact air temperature in any space.

It proved difficult to obtain accurate annual energy consumption for the IR heating due to the households' bills including all electricity uses such as: cooking, appliances, immersion water heating, Aga and electric vehicles. A few households also benefited from solar PV and batteries. Omitting those with electric vehicles or an Aga, annual consumption totals varied from 3236 kWh to 13,205 kWh with an average of 7729 kWh but a relative standard deviation of 43%. With such a small sample, it was impossible to reliably identify the main factors driving the significant variation but other studies with much larger samples across identical buildings (including passive houses) also show standard deviations of 50% which they attribute to the diversity of user behaviour.

Running costs didn't emerge as a major concern for these households relative to the value of quick, highly controllable warmth and their ability to reduce energy use (and cost) when and where it wasn't needed. But households often lacked a good grasp of the relationship between the amount they paid and the amount of energy they used and how this varied with both energy source and varying price rates.

In conclusion, I discuss the different characteristics of IR relative to a centralised space heating approach such as heat pumps in delivering a shared goal for the future of UK households in terms of thermal comfort and reduced energy.

Research method

With the kind cooperation of Herschel Infrared Heaters, 20 households were recruited from their customer base. An email invite was sent to all customers who owned multiple IR heaters with an incentive offered for taking part in the interviews. 20 respondents were then selected to reflect a variety of house types and occupancy. All had been using IR for over a year.

Interviews were conducted via Zoom and lasted 30-40 minutes. The recorded interviews were transcribed, entered into a spreadsheet and the resulting 10,500 comments categorised by topic. This enabled detailed analysis of the language people used to describe their experience and the frequency and pattern of responses on each topic.

The report is based on this analysis.

About the 20 households

Type of property	
Semi-detached or terraced	7
Old Cottage	5
Apartment/Flat	4
Bungalow	3
Detached house	1

Age of property	
Over 100 years old[3]	11
30 to 70 years old	5
Under 25 years old	4

Occupancy	
1 person[4]	6
2 people	6
3 people	5
4/5 people	3

Insulation	
Well insulated	8
Partly insulated	7
Poorly insulated	5

Previous Heating (before IR)[5]	
Gas or oil Central Heating	8

[3] This is a significantly higher percentage than the UK average of 21% houses predating 1919
[4] This corresponds with the average percentage for single person households in the UK
[5] 12 households had no mains gas connection.

Storage heaters	5
Electric convection radiators	3
Electric hot air system	1
Gas fires	1
Coal fires	1
Unknown	1

Why they chose IR Heating

In the majority of cases, making a choice on their future heating was triggered either by moving to a newly renovated home or a major retrofit to their existing one.

"*When we were renovating the house, I looked at various different heating systems*"

"*We had a blank canvas for starters*"

In 2 cases, it was triggered by an existing heat system becoming less efficient or old technology reaching the end of its life.

"because my previous boiler was condemned and I was thinking, 'Right okay….I should sort the heating out'"

"I had the most massive radiators, they were long, long radiators and I was always cold"

Considering and rejecting a heat pump

The most common alternative considered was a heat pump. 12 households seriously considered this but rejected it for one or more of the following reasons:-

Relative cost

"The cost of doing that (a heat pump) put me off because we were already spending a lot of money on the building"

"We had 3 quotes and they varied between, I think, £15,000 and £24,000"

They did NOT want a wet system (pipes) or underfloor heating

"...*we worked for private companies doing leakage work and so we're very wary about having a wet system under the floor … we used to get calls from people saying, 'Help, I've got a leak on our underfloor heating system'*"

"*My other option was air source heating but I just couldn't get my head around why it would be better to heat hot water and push that round the house rather than heat instantly*"

“I don’t want to have a whole wet system”

Unsuitable given their property’s lack of insulation

“*I came to the conclusion that it would not work in an older house like this which isn’t insulated from the ground up”*

“Because the house is not very well insulated, they said it’s not going to be cosy warm”

They only needed flexible top up heating

For a few, who were now fully insulated and had the benefit of good solar gain, they wanted more flexible options for occasional “top up” heating in some rooms.

“*We really went to town on the insulation and air tightness and realised, doing the heat calcs, that we didn’t really need heating..”*

“Underfloor heating works great if you turn it on in November and turn it off in March and you don’t have massive fluctuations in temperature, whereas, in this house, when the sun is shining we get a lot of solar gain naturally … so I wanted (heating) that was super controllable”

“I understand keeping a level ambient temperature, which is what you need to do with a heat pump, you can’t really control that quickly or shut down”

Anecdotal feedback about heat pump experiences

“*I was reading stories of people having nightmares with the amount of electricity they were using”*

“I’ve heard that retrofitting an air source heat pump isn’t always as successful as it should be and they make it out to be”

The main decision factors in choosing IR

What people <u>didn’t</u> want

Significantly, the IR decision was primarily driven by what people definitely did NOT want, namely either a heat pump, underfloor heating, centralised heating or wet systems.

“*I think it’s really old fashioned to have one system that heats the whole house rather than room by room…. that’s the advantage of the panels, you can do it independently. If you are in the living room, you only have the living room on*”

“*Rather than putting nasty old pipes and heaters everywhere*”

“I mean we don’t like underfloor heating which is the other thing that maybe we could have gone for”

This left relatively few alternatives

Given the factors they definitely wanted to avoid, people couldn’t find many alternatives. A couple of households mentioned looking at other electric radiator systems.

“*Yes, we’ve got very few walls as it happens. I did go backwards and forwards between would we do solid core wall hung radiators”*

“The quote came in at a 10th of the price of the house at £15,000. I don’t think that makes sense… there is only one wall that we could have put a radiator on anyway”

How did they know about IR?

A ⅓ of households had seen or heard about IR at some point - either through a friend or colleague or seeing something on TV.

“*We like watching things like ‘Grand Designs’ and that…..Charlie was putting it into a property and we’d never heard of it. Because we were looking at doing the extension and we’re all electric, I thought we’d do a bit of research on it*”

“*I think when I learned that The National Trust were trialling it that was one of the things that, kind of, really pushed me over the edge and thought ‘oh that will be a good choice, yes’*”

Learning about IR

But most people simply went online to look for options and happened to stumble across IR.

“*Yeah, maybe I just kind of stumbled across them and then started researching them, and looking at a lot of, you know, YouTube videos of how they’d work and….*”

“*I started looking at Scandinavia and Germany and stuff where these panel heaters were brought in 20-30 years ago. If the Germans are making them, it’s got to be good and efficient*”

Importance of experience

Having a chance to experience IR was important to most people given how unknown it was to them. Some managed to visit a showroom which convinced them.

“*So after hours of Googling, I found the infrared system. We went to the national home building exhibition in Swindon, and we found these panels that were on people ceilings and things like that*”

Others acquired a portable panel to try out.

"*I ordered a sample heater from Herschel to see how it worked. We put it in our lounge so at night we could see, when we were watching TV, whether it was working*"

"*That's one of the good things about the IR panels, you can plug them into a normal socket and try them … we did that. We liked how it worked*"

Initial scepticism

Some had to overcome initial scepticism

"*I dismissed infrared initially because I thought it was a gimmick… so initially I dismissed it and was looking at things like concrete filled radiators and all sorts of other heating systems*"

Felt a big risk

Many still felt nervous about the risk of going with something which was so unknown to them.

"*In the end, it felt like a huge risk to do the whole house*"

"*I was a bit nervous because I thought I don't really know anybody else that has done it. And I thought someone has to get it first, so…*"

3 factors swinging final IR decision

Flexible control

"*It was also having something that was very controllable*"

" *just to give a little top up when it's needed kind of thing*"

Needed to work with poor insulation, draughts or damp walls

"*I think the thing that really pushed me over the edge was I learned that it would go into the walls a certain amount which would help mould obviously which is useful for the older part of the cottage*"

"if you happen to have a draughty, non insulated house. It's one way of keeping warm without having to waste a huge amount of energy with convector heaters trying to heat the air"

The freedom of ceiling panels

"*The fact they're not on the walls, they're up on the ceilings*"

"We knocked down two internal walls downstairs so we've got very few walls as it happens"

How did people configure the panels?

The Herschel customers used an online configuration tool which, given the room dimensions and insulation levels, recommended the size and wattage of panels for each room. All but one household found this process straightforward. People also liked the freedom to tweak the panel specifications.

"*I went a little bit up in the lounge - just by a couple of hundred watts*"

Nearly all the households opted for ceiling panels over wall panels and subsequently cited ceiling panels as one of the major advantages of IR. A few were unable to fit ceiling panels in rooms as they had either beamed or Apex ceilings. They either opted for wall panels instead or one household chose Dimplex heaters in those rooms as they were easier for them to site. But they later changed these as "*the Dimplex really didn't cope with the size of room*".

Households often chose to site the ceiling panels directly above areas where they sat to eat, work or watch TV so they could feel the heat.

"*One of the benefits of being able to put panels on the ceiling, you can get nearer to where we sit to eat*"

"*Yes, one's straight above my head and one's above (my wife) on the settee*"

Wall panels with images (photos or artwork) were rarely chosen.

Operating patterns for IR heating

The Herschel IR is controlled through individual thermostats coupled to the panels in each room. People can configure their desired settings or timed schedules by operating the plug-in thermostat controls directly or via a mobile app from anywhere either in the house or remotely.

The 20 households controlled their IR heating by very different methods:-

6 households operated a purely ad hoc approach
2 households kept the heating on 24/7.
12 households operated a mix of timed schedules together with a high degree of ad hoc adjustment in the moment.

The ad hoc approach - heat just when and where you need it.

The ad hoc approach to heating meant simply switching on the panels in any particular room when they wanted to use that room or when they felt chilly in it. They then switched them off again either when they felt warm enough or had finished using that room.

Some used the mobile app to do this, others simply switched panels on and off at the wall.

"*We don't use it with the room thermostats, we just turn it on if we're too cold*"

"*You don't have to think about is it going to be cold later and warm up the house first, you can just put it on if you feel cold*"

"*I once tried keeping it on low all the time and I found that probably wasn't as efficient as just having it on in short bursts*"

The significant point is that this behaviour is not focussed on controlling the panels via the room thermostats (i.e. air temperature) but instead focussed on controlling how warm or not individuals feel or want to feel at the time they are in that room.

These people remark on how quickly they feel warm after switching on.

"*I can turn it on and I feel warm immediately"*

"I just use them manually as I want to use them.. I start to feel warm within about 10 minutes"

"*There's no point in heating a room all day just so it's comfortable when you come in it. You just need it on like 5 minutes before you want to come in and it warms the surfaces so you can sit on a warmer seat*"

And when they feel too warm, they just turn it down or off completely.

"*When we're in the front room, he tends to sit here near the (IR) mirror and I sit on the sofa which is under the heater. If I get a little warm, I just say 'let's turn this one off for a little while'"*

The danger, of course, is forgetting to turn them off

"*We've forgotten to turn them off a few times actually, got up in the middle of the night and realised it's piping hot in the living room!*"

Sometimes, people opt to have only one of the panels in a room switched on - the one by where they are sitting.

"*Our living room is very long and there is a little snug behind the bookshelf and often this is where we sit and read or watch something and there's just one panel exactly facing the sofa and often we don't even have the whole living room on, we just have that panel on and its' cosy"*

To some extent, these people are doing it to save money but also they tend to see heating rooms they are not in right now as wasted energy given how quickly they can warm them up.

"*Because we're watching the pennies more over the last year, we can just turn them on one room at a time*"

"*Given the infrared seems to heat quickly, personally I can't see why you would have it on all the time*"

"*To me, I feel like I'm not wasting masses of energy. I'm only heating what I need. With a water fed system, you need to allow extra time for things to get warm. This (IR) is instant, pretty instant so I like that flexibility*"

Those who use the mobile app, love being able to switch the heating on remotely to be ready for when they get home.

"*We use this app on my phone if we're out anywhere. We can actually say 'Right turn the heating on' on the way home, it's great!*"

"*At work if I've been out on a site meeting or something and it's freezing and I want the house to be really hot when I get home, you can just tell it to turn on all of that…. I just like being able to control it from anywhere*"

The opposite - a 24/7 approach to prevent a temperature drop

A couple of households operated the opposite extreme. They keep the IR heating on 24/7 at a fixed thermostat level so the house doesn't cool down enough that it would take a long time for the air temperature to get back to their preferred thermostat level.

"Where we are in the year, it's set at a certain temperature and it will stay there….It's on at 19 degrees probably all day at the moment… every room will be at 19 degrees but it will never go below that… the house stays at 19 degrees all night long"

"*24 hours. They're on at around about 20 on average. But if we feel that we're going to need some extra heat at some point in the evening, then we'll increase it maybe up to 23*"

One person was interested in experimenting by putting more heat in overnight to capitalise on cheaper electricity rates.

"*Between 12:30 and 4am, they give us a cheap rate which is 7p at the moment. My plan (if I can work out the timers) is to give them up to maybe 23 or even 24 degrees on that cheap rate to bring that infrared into the house overnight basically"*

These people tend to want to keep the house warm constantly because of how long they think the space takes to warm up if it's got cold.

"*If you walk into a house which has not been occupied for a week or something… you put the infrareds on, you know that they're not actually going to do very much for the first two or three days. They'll be heating the mass of the walls and the floor and the house in general… it's a slow thing … it's like an oil tanker!*"

People who control the heating this way can't imagine operating an ad hoc approach - only heating a room when you want it.

"*But I can't imagine for a second coming into a room and thinking 'but it's cold in here', let's give it a blast on 25 or something*"

"*I have it at 18 because I find the panels can't heat the room up very quickly.. I don't know if it's because it's a bit underspecified but I find they're generally more effective at keeping it warm rather than making it warm in the first place*"

Hybrid approach - combining a timed schedule with ad hoc adjustments

12 of the 20 households operated a hybrid approach with a few key rooms (or occasionally the whole house) on a timed schedule typically early morning and evening. But then they manually override this when they want the house or a particular room (or themselves) warm at a particular moment.

"*Well I have it coming on (timed) in the bedroom so I get out of bed and it's not freezing… then not in here until later in the afternoon*"

"Yes, I can just override and go to manual and take it up to a temperature I want to"

"It took a while to decide what the temperature would be set to. Because there would be times when we might put it on at a temperature and I just thought 'it's too hot in here' and other days thinking 'I need a blanket' "

A few households described how they were still experimenting to find the best mode of operation.

"*This has been very much a trial and error of understanding how they best work*"

Thermostat settings

For those who operate their heating primarily via thermostat settings, the modal temperature reported was 20°C. There were 3 outliers at the lower end (16-18°C) and 3 at the top end (22-23°C) although the latter were at certain times of day or in certain rooms.

A number of households reported how they struggled understanding and/or operating their thermostat control either directly or via the mobile app. This topic is discussed in the 'IR Disadvantages' section.

Main advantages of IR heating

The householders made 251 comments on the advantages of IR heating. Most comments referred to their ability to achieve thermal comfort quickly and flexibly whenever they needed it together with the distinctive thermal sensation IR delivers.

Flexible, ad hoc control

“I’ve yet to see something which is more controllable from the point of view of switching on and off”

“It’s flexible, it’s effective, it’s configurable, it’s controllable and it’s a much better option than any kind of convection heating”

“Last year when I was working from home, I could actually just heat the room I was in rather than heating the whole house which was perfect”

The heat effect is instant

“The best thing I like is that instant feeling … you just feel an instant warmth”

“I love the immediacy of it. I really like that you can switch it on and off, yes that’s the immediacy of it”

“With a water fed system, you need to allow that extra time for things to get warm. So it’s instant, pretty instant so I like that”

And it heats the person directly

“*If I sit on this seat, I can feel the heat… it’s a nice feeling*”

“When your underneath it, it’s absolutely beautiful”

“you can sort of feel it on you”

It feels like the sun

“It does feel like that kind of late autumn sunshine on your back when you’re out having a walk”

“I tell people that ask that it feels as if you’re on holiday and it’s hot and you’re sat outside - it’s exactly the same sense of heat versus traditional central heating which is all clammy”

“*We can sit here, turn it up a little bit and get this beautiful heat. It’s like, my goodness, we’re on the beach in the sun*”

Left on for longer it’s an ‘enveloping’ cosy warmth

These advantages seemed to refer to when the panels were on for longer periods in a room giving time for the thermal mass in the room to all be radiating heat.

“That warmth just envelops you”

“I mean it’s like all encompassing”

“You don’t have to go and hug the heat source because it’s all around you”

Contrasting sensation from convected air

“It’s not overbearing. I don’t get that blocked nose. I don’t get the stuffiness from central heating”

“My son has asthma and he doesn’t get that kind of tight, chesty, dusty feeling that he gets with normal heating”

People living in old, poorly insulated houses liked the fact that:

Draughts or open doors not a problem

“We don’t worry about stuff like draughts which is also really good”

“That you don’t have to worry about air escaping if you open a door or a window … whereas normally if you opened a door, you lost heat from the room”

And people like the fact that surfaces are warm.

Warm surfaces

“We’ve got tiles on the floor downstairs and these things will actually take the chill off the tiles .. we can walk around in bare feet fairly comfortably”

“I would say it’s quite comforting from the point of view if you put your hand on a surface you expect to be cold and it’s not. It warms the surface … you don’t even notice it’s working”

“The bathroom was great … it heats the tiles beautifully on the floor so you always get a cosy little bathroom”

Aside from the control and feel of the thermal comfort, people enthused about the option of ceiling panels freeing up space.

Ceiling panels

“S*uddenly you are free from putting radiators on walls - it’s lovely to have the freedom of furniture being able to go wherever you wanted*”

“*The aesthetics.. It looks modern and clean*” …*“rather than putting nasty old pipes and heaters everywhere”*

“*One of the benefits of being able to put panels on the ceiling, you can get more central to your room and nearer to where we sit to eat”*

And finally that the panels make for easy and flexible configuration

Modifiable easy/flexible installation

"*It's not hard to install.. Just put a surface conduit on and plug it in and you're up and running. It's brilliant*"

"*That was something I liked. If we've got a cold area, we can add an extra one because we've got lots of sockets. Somebody could just add it into any room they wanted"*

Main disadvantages of IR heating

The households made 91 comments about perceived disadvantages. 3 households saw no disadvantages at all.

The most frequently expressed disadvantages involved user interface issues with the mobile app and struggles and confusion over control of IR by thermostats.

Mobile App

The app issues didn't appear to be a feature of the IR technology but rather to do with general user interface and wi-fi coupling issues of the 'Smart Life' app**.**

"*I don't think much of that app actually. At least one time, it completely wiped all the setting on there and I had to set it all up again which was a bit irritating*"

"*I think they should consider making their own app to be honest… that would work a bit better with the pairing systems and all that sort of thing*"

Thermostat control issues

The thermostat control issues are more complex and possibly IR specific. They appear to involve a combination of technical issues with where the thermostat is sited relative to the panels (e.g. line of sight or not) …..

"*I mean it's difficult with infrared because it doesn't heat the air, only indirectly, the thermostats are not enormously reliable"*

"Each room is different. We've struggled a little bit. We've got all the wall mounted thermostats and again with the wall space it was tricky to know where to put the thermostat that they weren't directly near"

…. and the fact that people can't reliably distinguish between their own sense of how warm they feel (as a direct result of the IR heating them) and the air temperature in the room as signalled by the thermostat.

"Life is very different for infrared on temperatures because it's more about how you're feeling than what the actual temperature is"

"*The other day, you said you thought the thermostat was wrong because you felt it was warmer than it said but I didn't*"

"*She'll say 'it's hot in here' and I'll say it's only 19 degrees*"

Cold spots

Despite people exhorting the enveloping warmth of IR, a few complained about encountering unexpected cold spots in the room - particularly under a table or desk.

"*So the way the long wave panel works is line of sight so anything which physically blocks it, it can't get the heating underneath. So, if you put your feet under the table, you would certainly notice it. I noticed that in the kitchen"*

"So I just chuck a bottle of wine underneath the table so it's not being physically warmed up!"

"*When you're sat at the desk, your legs get cold… I had contemplated putting something under the desk*"

Takes a long time to reach temperature

In surprising contrast to the majority who were delighted by how quickly they felt the heating effect, 2 households reported that the room took a long time to achieve temperature.

"*Yesterday, it took 45 minutes to go up by one degree*"

"*It seems to take too long to warm up*"

The households concerned thought the panel wattage might be under specified for a particular room.

"*I think it's probably slightly underspecified. I think it's probably just about powerful enough but I don't think it would get to 20 degrees unless it was permanently on*"

But later investigation showed in one case that the panels weren't heating because the room temperature had already reached the thermostat setting. This is an example where occupants may have predicted they would feel warm at a particular set room temperature (18°C) but weren't and needed more direct heat.

Ceiling fitting issues

"The fact that we've only got a narrow strip of ceiling and then it slopes down with the coombe ceiling, you can't put them on the ceiling"

"There was the whole problem of how do you fix them onto the ceiling of an old building"

Energy Efficiency

Difficulties in obtaining accurate figures

The hope was to get a sense of the annual electricity consumption of IR heating for each household. Not surprisingly, this proved messy and hard to analyse reliably. This was for a variety of reasons:-

4 households were unable to provide an annual figure at all.

11 of the households had one or more additional forms of heating, as shown below, which would either reduce or add to their electricity heating totals.

NONE	9
Log burners	6
Electric Underfloor	2
Electric towel rails	2
Portable electric radiator	2
Dimplex radiators	2
Electric Aga	1
Plug in biofuel heater	1

The most common was log burners which they regularly used to help heat their living rooms in the evening. Given the effectiveness of log burners, this would obviate the need for IR heating in that room when these were alight.

“I’ve got two log burners … oh my God yes, they just create that cosy heat, don’t you think”

“The one in the lounge last winter I lit every evening probably”

9 households had one or more additional sources of electric heat. Depending how often these were used, these would both reduce some IR panel use but also add to some degree to the annual consumption figures. Most notably, an electric Aga heating a large kitchen apparently consumed 18,000 kWh a year meaning the IR panels were rarely required except upstairs.

5 households stressed the impact which solar gain had on their winter heating needs.

“*In this house, when the sun’s shining, we get a lot of solar gain*”

“*In the afternoon, the sun heats up the front of the house… it gets really toasty*”

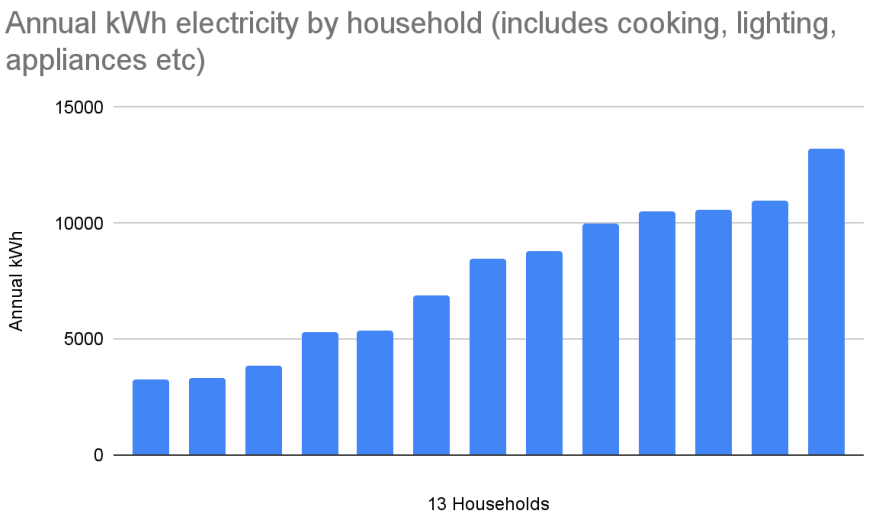
5 households had the benefit of solar PV panels combined with batteries in 2 cases. This reduced their annual electricity consumption by some unknown amount.

4 houses used gas boilers to heat their water. All the rest used electricity so this would account for possibly 17% of their annual electricity consumption.[6]

3 households owned electric vehicles which would add considerably to their annual consumption[7] and they had no way of isolating this effect so I had to eliminate the figures for those households.

Obviously all appliances, cooking and lighting were included in the figures provided.

The chart below shows the range of kWh figures for annual electricity consumption for the 13 households who could provide figures and did not possess electric vehicles or an electric Aga.



User variance

The annual consumption figures ranged by a factor of 4 from 3236 kWh to 13,205 kWh. The mean was 7729 kWh but the relative standard deviation was high (43%). This level of variation is a problem with such a small sample but other studies with much larger samples report deviations of +/- 50% from the average kWh consumption even in identically constructed and even Passive homes. These large deviations are attributed to a broad spectrum of user behaviour.[8]

It's difficult to tease out the factors which had the most effect on the kWh variation especially given the small numbers involved but these tables might offer some clues for further

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[6] https://www.directenergy.com/learning-center/how-much-energy-water-heater-use
[7] Average UK electric cars consume ~33kWh for every 100 miles travelled.
[8] https://www.researchgate.net/publication/340014165_Are_the_energy_savings_of_the_passive_house_standard_reliable_A_review_of_the_as-built_thermal_and_space_heating_performance_of_passive_house_dwellings_from_1990_to_2018_full_text_see_comments

investigation although the size of the relative standard deviations and the probability that these are attributable to variation in user behaviour undermine any clear conclusions.

No. occupants	Average kWh	Relative SD
1 person	5964	64%
2 people	9457	10%

1 person households used an average of 37% less energy than 2 person households (which one might expect) but, even in those households, the variation was the dominant factor.

Size of House	Average kWh	Relative SD
1-2 beds	6588	52%
3 beds	8347	43%

Type of house	Average kWh	Relative SD
Cottage	8574	48%
Apartment	5610	54%
Semi /Terrace	9434	22%

Insulation	Average kWh	Relative SD
Good	9053	47%
Part	7832	28%
Poor	6588	52%

The insulation averages are in reverse order to expectation although it's worth remembering that poor insulation should have less impact on IR heating due to it heating the thermal mass rather than the air.

Daytime occupation	Average kWh	Relative SD
All day	7124	48%
Part	10119	21%
Out	5068	51%

5 households mentioned frequently checking their Smart meters but this did not appear to lower their annual consumption.

Given that consumption figures from larger studies are also distorted by user behaviour effects, it's very difficult to identify key factors in space heating energy consumption.

Individual differences in thermal comfort

In 11 households, people reported differences in individual thermal comfort levels between family members. In all but 2 cases, the women tended to feel colder than the men. These individual differences correspond with earlier studies[9].

"*She feels the cold a lot more than I do*"

"*The reality of it that I know she likes to be warm so we have a warm house and probably warmer than I would naturally have it"*

(woman) *"Because I'm someone who feels the cold, I always have done so I will always be nagging to put the heating on"*

"My wife, she gets cold when we go to Cyprus so I don't think she's a very fair judge"

"He doesn't feel chilly … he lives in shorts all year long!"

"If I said to him, 'shall we put the heating on?', he'll just be too hot"

"We're complete opposites, he's the one who likes to cover up"

Other studies show wide variation in the room temperatures at which individuals feel comfortable, chilly or warm[10]. There was indirect evidence from householders' comments that IR heating might help alleviate differences in comfort levels between individual householders because sitting or standing directly below an IR panel can warm an individual up directly regardless of room temperature.

"*Although the air might be cold, you are still getting the benefit from the heat*"

"*They (IR panels) actually heat me and I think that's the important bit"*

How did people view IR heating cost?

Cost a lesser factor

The households presented a mixed and somewhat confused picture when discussing heating costs. Only 3 households mentioned cost as an IR disadvantage and only 2 (perhaps more price sensitive) households accounted for 25% of the 74 comments made about cost.

"*Because I think they're* (IR panels) *not very cheap to run perhaps as much as advertised"*

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[9] https://theprospectory.files.wordpress.com/2022/04/domestic-heat-trial-report.pdf

[10] https://www.researchgate.net/publication/301221979_Diversity_in_Thermal_Sensation_drivers_of_variance_and_methodological_artefacts

"*My bills have gone up a lot.. I think it's about £200 a month which is a lot more than it used to be*"

For many, cost seemed to be a lesser factor compared to the value of having quick thermal comfort which they could control.

"*I did lots of reading about the technology and how it works, I did no reading at all about the cost of electricity or how that happens… I'm very happy because I hated the radiators"*

"I didn't used to be warm and now I am!"

" I don't really feel cold any more which is perfect"

Figuring out cost of heating is confusing

Many households seemed unsure or even baffled trying to figure out the relative cost of running their heating given all the recent price rises and changes in pricing structures and the fact their electricity bills included all uses of electricity not just heating. If a bill was higher than expected, they sometimes couldn't tell whether that was a rise in their energy use (rather than price) and, if so, from what source.

"*When we first switched on the heating (a few weeks ago), it was significant how the numbers went up… but that was just when the prices went up*"

"It's quite hard to judge because I guess we judge how much something is using by how much it's cost!"

"I don't know about electricity wise but cost wise it's been completely fine"

"*As far as we can tell, the running costs are substantially less than we were experiencing before with night storage and solid fuel"*

Cost driving ad hoc behaviour

In a couple of cases, electricity prices were a key factor driving ad hoc behaviour

"*We don't even use it with room thermostats, we just turn it on if we're too cold. I think, to be honest obviously because of energy prices"*

"*Because we're watching the pennies more over the last year, we can just turn them on one room at a time*"

"*I mean the only bad thing is the cost of running it but obviously we've mitigated that by one of the other factors of it is that you can just turn it on and off as you need it*"

Planned changes with rising costs

Not many people said they planned to change their behaviour but welcomed the flexibility of IR enabling them to do so.

"*I've always been quite frugal. I'm not like some people who put it on all the time. I've always planned it around when we're going to be in each room . so I probably won't change*"

"*I probably won't change anything about my energy habit***"**

"If we felt downstairs was becoming too expensive, we would turn the panels off where we're not sitting"

Others are looking at ways, not to reduce energy, but to make better use of dual tariffs and solar batteries.

"My plan is, if I can work out the (infrared) timer on this is to put them on to 23 or even 24 on the cheap rate to being that infrared heat into the house, overnight basically for maybe a couple of hours"

"*We'll probably go on like a dual tariff and store up the battery overnight when it's cheaper*"

Concluding discussion

The study was motivated by the challenge of how to keep people comfortably and affordably warm in their diverse range of housing whilst reducing fossil fuel and avoiding wasting energy. The findings show that IR's ability to heat people flexibly, directly and quickly when and where in the house they need it delivers thermal comfort to people with different needs for warmth and in a range of housing types. It also enables a reduction in wasted energy where it's not currently needed.

Thermal Comfort

The householders relished the fact that the flexibly controlled IR panels could heat them quickly and directly without being tied to the air temperature in the room. And, if they left the panels on for longer periods, it created an enveloping warmth based on the radiation from all the thermal mass surrounding them. People also preferred the sunlike sensation to the sensation of warm, convected air.

Because of the reduced reliance on air temperature for thermal comfort, people in older and poorly insulated properties found that IR worked well in keeping them warm despite residual draughts.

IR challenges the long accepted relationship between air temperature in buildings (as controlled by thermostats) and thermal comfort. Most notably, the UK's Standard Assessment Procedure (SAP) for Energy Rating of Buildings[11] is based on heating the air in buildings to an agreed target temperature which will deliver 'universal thermal comfort'.

[11] https://www.gov.uk/guidance/standard-assessment-procedure

Thanks to recent technological developments, this standardised air temperature approach now includes continuous monitoring and adaptation to outside temperatures. In well insulated houses, the goal is to create uniform, fully automated 'indoor climates' which need only low fluid temperatures (less energy) to maintain a constant, standardised level of space heating (19-20°C) delivering thermal comfort with minimal (if any) householder intervention.

But one difficulty with this standardised approach is that individuals (even within the same space) vary in their thermal comfort due to a combination of physiology, gender, age, health and current activity levels. For example, occupants in one study[12] recorded thermal comfort ratings across the entire scale from '*cold*' to '*hot*' in both top A/B energy rated dwellings at room temperatures of 20°C to 26°C and in bottom F rated energy dwellings at room temperatures of 14°C to 24°C . The actual room temperature accounted for only 11% of the variance in people's thermal comfort ratings.[13] A recent study[14] recorded some participants feeling "chilly" in a room temperature of 21°C while others felt "too warm" in a room temperature as low as 17°C.

The key factor is that air temperature doesn't warm us (unless it rises above 37°C), it simply reduces the rate at which we lose heat. Any subjective assessment of room temperature is based on 'feels like temperature'[15] relying on our sense of losing heat from our skin to the surrounding air[16] and our senses respond primarily to contrast such as arriving home from a warm or cold outdoors or moving to a different room. 'Feels like temperature' will always be highly contextual and personal and not necessarily correlated to any thermostat reading[17]. This probably explains the confusion which sometimes occurs with IR heating between how warm someone feels (sitting underneath a panel say) and the actual air temperature which the thermostat shows.

If the connection between individuals' thermal comfort and air temperature is always somewhat indirect and personal, then it can't be easily standardised (or even sensed!)[18]. In contrast, IR provides a means for individuals to heat themselves directly and quickly in whatever space they happen to be inhabiting - the equivalent, as our householders described, of moving to sit in the sun when the air temperature is low.[19]

Experiments have also shown a psychological effect that, where people know they can control their own required heat level (as IR panels flexibly allow), they show better thermal

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[12] https://www.sciencedirect.com/science/article/pii/S0378778816311057
[13] Thermal comfort of heterogeneous and dynamic indoor conditions — An overview - ScienceDirect
[14] https://theprospectory.files.wordpress.com/2022/04/domestic-heat-trial-report.pdf
[15] https://blog.metoffice.gov.uk/2012/02/15/what-is-feels-like-temperature/
[16] Hence the expression "Feels like temperature" https://blog.metoffice.gov.uk/2012/02/15/what-is-feels-like-temperature/
[17] The obvious example of sitting outside in the sun on a cold winter's day.
[18] How humans actually sense heat is not fully understood and was the subject of a Nobel Prize in physiology last year https://www.understandinganimalresearch.org.uk/news/2021-nobel-prize-in-medicine-for-discovering-how-

[19] This might also account for the enduring popularity of log burners even in centrally heated properties.

comfort ratings at the same room temperatures.[20] Controlling any central heating system - especially one automated to maintain a fixed micro climate - will not allow easy heat source adjustment to quickly affect someone's thermal comfort in the moment.

Energy efficiency

For most of the past 50 years since the advent of central space heating, energy consumption from heating large volumes of air was not considered an issue. This was because of little understanding of carbon emissions from fossil fuels and because gas was both ‘on tap’ and cheap.

Given climate change, the depletion of oil resources and the rising cost of heating, energy efficiency is now considered a critical issue.

To that end, the government’s SAP methodology is designed to assess how much energy any dwelling will consume when delivering a defined air temperature required for ‘universal thermal comfort’. The assessment is based on standardised assumptions for occupancy and behaviour which (at least in principle) enables a like-for-like comparison of dwelling performance. The advantage is that related factors, such as fuel costs and emissions of carbon dioxide (CO2), can be determined from such an assessment.

But, aside from the thermal comfort issues discussed above, the SAP approach of maintaining a constant air temperature also requires considerable energy because of the large volume of air involved, i.e. 1 kW for every 10 square metres of the home[21] and an average 3 bed house is 100 square metres. And, as heated air constantly moves to where it’s colder, open plan housing or leaving doors open makes this worse. This is why our old and poorly insulated housing stock is such a disaster for maintaining constant air temperatures and why insulation and retrofitting is so badly needed to achieve reasonable thermal comfort and not waste energy.

Based on our findings, IR heating *should* prove competitive on energy efficiency precisely because it warms people directly without having to warm all the air in a room to a target temperature to achieve that. And with IR, the air will warm throughout a space over time as the thermal mass heats and radiates back. And, most critically, the findings show that some people only turn IR panels on for short bursts just to feel warm in a particular space for the short time they need it.

So, how did IR compare on its relative energy efficiency?

Disappointingly, the answer is it’s hard to tell. In the case of our study, it wasn’t possible to reliably compare the annual kWh figures obtained with other forms of space heating because they included significant additional electricity consumption in the home for: cooking, immersion water heating, lighting, appliances, additional heaters and even electric vehicles. Also, the total time IR panels are operating in a year isn’t yet recorded separately from other

[20] https://www.sciencedirect.com/science/article/pii/S0360132316303560#bib126
[21] https://www.greenmatch.co.uk/green-energy/central-heating-capacity

consumers of electricity[22] The range of recorded figures (with an average of 7729 kWh) did compare well with the average UK household figure of 12,000 kWh based on traditional central heating.

Arguably, the most telling result from this study was the high (43%) standard deviation in annual kWh consumption with similarly high variance even in subsets of roughly equivalent households in terms of housing type or insulation levels. This made it impossible to tease out contributory factors reliably.

Significantly, larger and better controlled studies report standard deviations of 50% in energy consumption even when buildings are identical and even including Passive houses[23]. This huge variance is attributed to the broad spectrum of user behaviour which is very difficult to either predict, measure or control.

An important comparison point for IR is obviously air source heat pumps but, despite their higher profile, it is difficult to find reliable sets of consumption figures across households. Online, heat pumps sometimes cite 4,000 kWh/yr but this appears to be an estimate based on a COP[24] rate of 3 together with the UK average of 12,000 kWh. One 2021 government report[25] based on theoretical modelling of air source heat pumps across 12 common household types shows average kWh consumption ranging from 3170/kWh/year to 9480 kWh/year.

Heat pumps should win on reducing energy consumption given their impressive multiplying factor of 3 kWh (or in many cases more) of heat for every 1kWh electricity. But, heat pumps operate as central heating systems configured to heat space via underfloor heating, piping and large radiators using lower fluid temperatures than traditional gas boilers. This means they need to be powered for longer periods to deliver warmth and maintain target air temperatures. If householders do use IR panels to heat themselves primarily on an ‘as needed’ basis then it is possible (although not yet verifiable) that the overall energy involved might be comparable.

It is noteworthy that a couple of fully insulated houses opted for IR panels over a heat pump system because they found they barely needed anything other than an occasional heating top up in many rooms. This suggests that one future scenario for some households is a heat pump which delivers a low background heat 24/7 in winter to stop the building ever dropping below, say, 16°C or so with IR panels deployed in certain rooms to give a radiant heat top up either when people are sitting and relaxing or when they are only likely to use a room for a limited time.

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[22] Although I understand this will be available for some Herschel products from January 2023.
[23] https://link.springer.com/article/10.1007/s12053-020-09855-7
[24] Coefficient of performance - i.e. the pump delivers 3 kWh of heat for every 1 kWh of electricity deployed. COP figures range depending on latest technology development, the type of house and outside temperatures.
[25] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1104051/CODE-Final-Report-WHOLE-FINAL-v20.pdf

More research needed on user behaviour and thermal variation

Heat pump and IR performance data based on normal household usage instead of theoretical models are badly needed especially as it's unlikely that heat pumps can avoid the same large user behaviour variance as other systems unless intelligent operation becomes fully automated. But people (given their varying thermal comfort and behavioural patterns) may or may not be happy to concede all thermal control to a standardised indoor climate.

Theoretical models are valuable for generating universal heating standards because they are based on known physics and engineering performance parameters. But they disguise the large distorting effect, not just of domestic building vagaries, but also of user behaviour. As an experimental psychologist, I appreciate why engineers are keen to avoid unpredictable, uncontrollable human behaviour wherever possible as this valuable human asset messes up controlled experiments and clean, quotable statistics. But, if user behaviour does account for 50% of energy consumption variance, then it's not ultimately helpful to eliminate people from heating trials nor try to automate them out of existence.

One possibility is to design comparative heating studies of a different kind with a greater focus on recording and understanding behaviour patterns in the home in relation to energy consumption and thermal comfort. For example, which rooms or areas of rooms do people frequent, how many people, for what activities and for how long? This would be combined with intermittent sampling of individual thermal comfort within households and what people alter to affect this. This might not correspond closely with thermostat readings at all - depending on how active people are, what they are wearing and what air temperature they've recently moved from.

Finally, the study showed that people are confused by energy efficiency because it's most commonly expressed in terms of price rather than units of energy. This confusion has worsened since the recent change of pricing. The government, energy suppliers and smart meters all have a role to play in helping people understand energy efficiency separately from the current price they happen to be paying. For example, people think electricity is less energy efficient than gas or oil because it costs far more per unit when it is actually 100% efficient unlike fossil fuel boilers. Improving this communication will enable people to act more effectively on reducing energy and costs themselves.

In conclusion, the findings from these 20 IR households challenge our thinking on centralised controlled heating, thermal comfort standards and energy wastage. If we decouple heating people from heating air and offer people flexible 'in the moment control' over their own warmth, the game changes. It may also be more resilient to the vagaries of home insulation levels, individual physiology and user behaviour.