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АНГЛИЙСКИЙ ЯЗЫК

HEAT POWER ENGINEERING

Учебное пособие

Санкт-Петербург
2022

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Утверждено Редакционно-издательским советом ВШТЭ СПбГУПТД

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Учебное пособие соответствует программам и учебным планам дисциплины «Иностранный язык. Английский язык» для студентов, обучающихся по направлению подготовки 13.04.01 «Теплоэнергетика и теплотехника». Разработано для изучения академического аспекта английского языка. Учебное пособие посвящено практическому овладению научной речью в сфере профессионального общения.

Пособие предназначено для подготовки магистрантов очной и заочной форм обучения.

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ОГЛАВЛЕНИЕ

ПРЕДИСЛОВИЕ

Данное учебное пособие разработано для студентов магистратуры Института энергетики и автоматизации, обучающихся по направлению подготовки «Теплоэнергетика и теплотехника», для изучения академического аспекта английского языка.

Основной задачей курса «Иностранный язык. Английский язык. Heat Power Engineering» является обучение практическому владению научной речью в сфере профессионального общения.

Основой построения программы обучения является направление, или аспект, «Язык для специальных целей» (Language for Specific Purposes – LSP). Данный аспект предполагает развитие навыков, необходимых для освоения соответствующего регистра речи.

Целью данного курса является подготовка высококлассного специалиста международного уровня, одной из составляющих в будущей профессиональной деятельности которого станет языковая грамотность и культура речи. Задачи, стоящие перед студентом: закрепление навыков правильного английского произношения (Oxford English); знание особенностей построения научно-технических текстов из оригинальных источников и овладение техникой работы с ними; самостоятельный поиск и извлечение информации на иностранном языке и ее дальнейшее применение в профессиональной сфере; умение поддержать и вести беседу с зарубежными специалистами на темы широкого спектра с учетом различных деловых культур.

В аспекте «Язык для специальных целей» осуществляется: развитие навыков чтения специальной литературы с целью получения информации; знакомство с основами перевода литературы по специальности. Обучение языку специальности ведется на материале произведений речи на профессиональные темы.

Освоение учащимися фонетики (для правильного чтения учащимися технических терминов и аббревиатур), грамматики, синтаксиса, словообразования, сочетаемости слов, а также активное усвоение наиболее употребительной лексики и фразеологии английского языка происходит не в виде заучивания свода правил, а в процессе работы над связными, законченными в смысловом отношении текстами.

Обучение предусматривает: а) формирование фонематического слуха посредством аудирования; б) формирование практических навыков и умений чтения и перевода; в) развитие устной речи; г) отработку грамматического материала с последующим использованием в разговорной речи; д) формирование навыков самостоятельной работы.

В программу самостоятельной работы студентов входят освоение теоретического и практического материала, разобранного вместе с преподавателем на занятиях, подготовка к практическим занятиям в форме словарной работы со статьей, запоминание произношения и написания новых слов и выражений, построение и разучивание диалогов по учебной программе, формирование умений свободно выражать мысли на изучаемом языке, составлять эссе и делать презентацию по заданной теме.

ЧАСТЬ I. ФОНЕТИКА

Английский алфавит

1.	A a	[eı]	14	N n	[en]
2.	B b	[bi:]	15	O o	[əʊ]
3.	C c	[si:]	16	P p	[pi:]
4.	D d	[di:]	17	Q q	[kju:]
5.	E e	[i:]	18	R r	[ɑ:]
6.	F f	[ef]	19	S s	[es]
7.	G g	[dʒi:]	20	T t	[ti:]
8.	H h	[eıtʃ]	21	U u	[ju:]
9.	I i	[aı]	22	V v	[vi:]
10.	J j	[dʒeı]	23	W w	['dʌbl'ju:]
11.	K k	[keı]	24	X x	[eks]
12.	L l	[el]	25	Y y	[waı]
13.	M m	[em]	26	Z z	[zed]

Чтение окончания -s (-es)

-s читается **[z]** после гласных и звонких согласных:
lives, mills, stands, forms, stays, tries, trees, goes, studies, cars;

[s] после глухих согласных:
likes, parents, flats, stops, asks, maps;

[ɪz] после шипящих и свистящих звуков [s, z, ʃ, ʧ, ʒ, ʤ]:
sizes, boxes, watches, bridges, colleges, washes, wishes, gases, a'ddresses, pages, uses, branches, classes.

Примечание: помните, что окончание -s бывает у существительных и глаголов.

Не следует путать:

– у существительных окончание **-s** – признак *множественного* числа: papers (бумаги, документы), books, students, forms (формы), lights (огни);
– у существительных окончание **-'s** – признак *притяжательного* падежа (отвечает на вопрос **чей?**). Сравните:

my friend	мой друг
my friend**s**	мои друзья
my friend**'s** work	работа моего друга
my friend**s'** work	работа моих друзей

– у глаголов окончание **-s** – признак третьего лица *единственного* числа во времени Present Simple: he (she) reads – он (она) читает, he (she) knows – он (она) знает, he (she) goes – он (она) идет, he (she, it) lights – он (она, оно) освещает, it snows – идет снег, he (she, it) influences – он (она, оно) влияет.

Задание 1. Прочтите следующие слова:
advises, matches, prizes, sheets, thinks, works, photos, stories, shows, throws, pulps, cooks, rises, 'services, causes, forces, cities, maps, pages, judges, passes, sciences, tries, answers, presses, places, praises, stops, asks, wishes, takes, papers, fibers, chemicals, inches, roots, de'velops, 'surfaces, pro'duces, makes, wastes, 'furnaces, 'purposes, woods, 'processes, 'influences, bags, 'methods, 'differences, 'differs, 'offers, su'ggests, pro'poses, studies, reaches, runs, scientists.

Чтение окончания -ed

-ed читается **[d]** после звонких согласных и гласных:

formed, dried, tried, closed, played, studied, changed, functioned, contained, used, planned, employed;

[t] после глухих согласных:

worked, watched, stopped, helped, liked, stressed, forced, walked, cooked, pulped;

[ɪd] после согласных **t** и **d:**

waited, invited, wanted, decided, visited, de'manded, com'pleted, su'pported, acted, di'rected, consisted, 'limited, tested, resulted.

Задание 2. Прочтите следующие слова:
washed, di'vided, de'veloped, burned, im'proved, ab'sorbed, pro'duced, helped, learned, 'regulated, mixed, 'generated, 'operated, pro'vided, liked, in'tended, turned, ex'tracted, com'bined, suited, bleached, 'separated, 'processed, trained, con'verted, solved, missed, di'ssolved, re'mained, in'cluded, heated, produced, po'lluted, 'influenced, manu'factured, con'taminated, changed, looked, littered, a'ttracted, dropped, e'quipped, printed, planted, warmed, lasted.

ЧАСТЬ II. ГРАММАТИКА

Перевод двучленных и многочленных атрибутивных словосочетаний, выраженных существительными («цепочки» существительных)

Инструкция 1. Двучленные или многочленные атрибутивные словосочетания, или «цепочки» существительных, – это словосочетания, состоящие из существительного и определений, расположенных слева от него.

В качестве левого определения могут быть *существительные* (от двух до пяти или шести). Существительным могут предшествовать: прилагательное, причастие, местоимение или числительное, а также сочетания из этих слов, соединенные дефисом.

Необходимо обратить внимание на то, что внутри такого сочетания *слова не отделены друг от друга ни артиклями, ни предлогами, ни запятыми*:

strong acid pump;
white water treatment equipment;
high consistency oxygen bleaching system.

Для перевода «цепочки» существительных важно найти в ней основное слово. Помните, что *основным словом* любой «цепочки» существительных является *последнее существительное, с которого и следует начинать анализ* такой «цепочки». Все существительные и другие части речи, стоящие слева от основного слова, являются *определениями* к нему (отвечают на вопрос «какой?», «какие?»). Справа от основного слова, указывая на то, что «цепочка» закончилась, может стоять новый артикль, предлог, местоимение, прилагательное, причастие или глагол-сказуемое с предшествующим наречием или без него.

I. Перевод двучленных словосочетаний («цепочки» состоят из двух существительных)

Инструкция 2. Перевод двучленных словосочетаний *начинаем с последнего существительного*, а существительное, стоящее слева, переводится *существительным в родительном падеже.*

Образец:	1) pulp quality	- качество целлюлозы
	2) water level	- уровень воды
	3) wood consumption	- расход древесины
	4) cooking time	- продолжительность варки

stock (волокнистая масса) preparation; stock temperature; stock production; sheet properties; sheet formation (формование).

Инструкция 3. В «цепочке», состоящей из двух существительных, первое переводится *прилагательным.*

Образец: 1) wood fiber - древесное волокно
2) gas bleaching - газовая отбелка
3) cooking acid - варочная кислота
4) paper stock - бумажная масса

wood chips; acid digester; wood species (порода); sulphite digestion; oxygen bleaching; stock pump; laboratory tests; spruce chips; bleaching plant (отдел); hand operation; pine chips; water vapor; cooking process; bag paper.

Инструкция 4. Перевод «цепочки» существительных начинаем с последнего существительного, а первое переводим *существительным с предлогом (в, из, на, для и др.).*

Образец: 1) hardwood pulp – целлюлоза *из* лиственной древесины;
2) drying costs – затраты *на* сушку (затраты, связанные *с* сушкой)
3) pollution control – борьба *с* загрязнением

digester pressure; softwood pulp; acid (кислая среда) hydrolysis; linen (льняное тряпье) paper; board products; evaporator (испаритель) gases; hardwood sulphite pulp.

II. Перевод многочленных словосочетаний («цепочки» существительных состоят из трех и более существительных и других частей речи)

Инструкция 5. При переводе многочленных словосочетаний рекомендуем:

1) перевести последнее существительное «цепочки»;
2) разбить остальную часть словосочетания на *смысловые группы* и перевести их (внутри смысловой группы анализ проводится слева направо);
3) перевести все словосочетание (всю «цепочку»), следуя справа налево.

Образец: 1) stock mixing| *system* – система для смешивания массы;
2) wood fiber| *products* – изделия из древесного волокна;
3) water quality| *results* – результаты по качеству воды;
4) stock preparation| machine *operation* – работа машины по приготовлению массы.

В данных словосочетаниях – по две смысловые группы. Основное слово выделено курсивом.

Переведите, следуя инструкции 5.

а)
chip packing (уплотнение) device;
strong acid pump;

stock preparation machine;
paper machine operation;
fiber suspension flow;
b)
paper formation (формование) time;
chlorine dioxide generation (образование);
pulp preparation operation (процесс);
steam flow rate;
headbox (напорный ящик) control (регулирование) system;
c)
chain (цепь) length distribution (распределение);
fiber length distribution;
chemicals recovery system;
heat transfer (передача) coefficient;
water conservation costs (затраты);
d)
fiber wall thickness;
cooking liquor circulation;
gas diffusion constant;
quality control method;
paperboard test (анализ) result;
e)
plant design changes;
cooking liquor pressure;
stock preparation equipment;
air pollution (загрязнение) problem;
air pollution abatement (уменьшение);
water purity level (степень).

Образец: sodium base| sulfite *pulping*
Sulfite pulping – сульфитная варка;
Sodium base – натриевое основание;
= сульфитная варка на натриевом основании.

Переведите, используя образец:
various cooking liquor composition;
high yield sulfite pulp;
constant vapor phase region;
ammonia base sulfite pulping;
caustic soda recovery (регенерация) system;
white water (оборотная вода) treating equipment;
paper mill steam supply (обеспечение);
particle size distribution determination;
calcium base cooking liquor.

Инструкция 6. Если «цепочка» существительных *начинается с прилагательного,* необходимо обратить внимание на то, *к какому слову оно относится.*

Образец: 1) high yield pulp – целлюлоза с высоким выходом;
2) new sheet structure – новая структура листа;
3) maximum cooking temperature – максимальная температура варки.

Инструкция 7. В состав «цепочки» существительных в качестве определения могут входить числительные, местоимения, причастия, существительные в притяжательном падеже и т. д. Обратите внимание, *к какому слову эти определения относятся.* Помните, что *основное слово словосочетания – последнее существительное.*

Образец: 1) this high pressure steam – этот пар высокого давления;
2) rate determining factor – фактор, определяющий скорость.

Инструкция 8. Иногда одно из слов «цепочки» существительных необходимо перевести *поясняющими словами (группой слов).*

Образец: 1) paperboard machine – машина *для выработки картона;*
2) chipping operation – предприятие, *осуществляющее заготовку щепы;*
3) bark products – продукты *переработки коры.*

Страдательный залог глаголов (The Passive Voice)

Инструкция 1. Страдательный залог глагола употребляется в том случае, если само *подлежащее не действует*, действие совершается *над ним*.

Глагол-сказуемое в страдательном залоге можно найти в предложении по вспомогательному глаголу ***"to be"*** в соответствующем времени, лице и числе и ***Past Participle*** (причастию прошедшего времени смыслового глагола).

Примечание 1

Past Participle (Participle II) образуется путем прибавления окончания -*ed* к правильным глаголам. Если глагол неправильный, употребляется его *3-я форма* (built, taken, written…). Рекомендуем повторить 3 формы неправильных глаголов.

Примечание 2

Обратите внимание на то, что Past Participle правильных глаголов совпадает по форме со временем Past Simple (produced, achieved). Определить их можно только в контексте. (Подробнее о Past Participle см. в разделе, посвященном причастиям).

Таблица 1 – Страдательный (пассивный) залог. Образуется: глагол to be (в соответствующем времени) + Participle II

Правила и способы перевода	Пример	Перевод
1. Страдательный залог показывает, что действие глагола-сказуемого направлено на лицо или предмет, выраженный подлежащим. В ряде случаев подлежащее переводится прямым или косвенным дополнением и ставится, соответственно, в форме винительного или дательного падежа.	**He** was given a task.	**Ему** дали задание.
	We were informed that a new idea had been advanced recently.	**Нас** информировали, что новая идея была выдвинута недавно.
2. Если после глагола в пассиве есть дополнение с предлогом **by** или **with**, то оно указывает, кем или чем производится действие. Предлоги переводятся «путем», «при помощи», «посредством» либо соответствуют творительному падежу и не переводятся.	The calculation is done **by computer programs.**	Подсчеты делаются **компьютерными программами** (**при помощи** компьютерных программ).
	The production line is supplied **with raw material.**	Производственная линия снабжается **сырьем.**

Продолжение табл. 1

Правила и способы перевода	Пример	Перевод
3. Сочетанием глагола «быть» с кратким страдательным причастием с суффиксами -н- или -т-. Глагол «быть» в настоящем времени опускается.	The mill is built by the workers. are built was built were built has been built have been built shall/will be built will be built	Фабрика построена рабочими. построены была построена были построены была построена были построены будет построена будут построены
4. Глаголом на **-ся** в соответствующем времени, лице и числе.	The goods **are being sold** with profit. **were being sold**	Эти товары **продаются** с прибылью. **продавались**
5. Глаголом действительного залога в 3-м лице множественного числа, в неопределенно-личном предложении.	The company’s account **is checked.** was checked will be checked	Отчет компании **проверяют.** проверили будут проверять

Окончание табл. 1

Правила и способы перевода	Пример	Перевод
6. Глаголы с относящимся к ним предлогом, которые переводятся также глаголами с предлогом: to depend on – зависеть от to insist on – настаивать на to look at – смотреть на to rely on – опираться на to speak of (about) – говорить о to refer to – ссылаться на, называть to deal with – иметь дело с и др. переводятся глаголами в неопределенно-личной форме, причем соответствующий русский предлог ставится перед английским подлежащим.	The new plant is much spoken **about**. This article was often referred **to.**	**О** новом заводе много говорят. **На** эту статью часто ссылались.
7. Глаголы без предлогов, которые переводятся глаголами с предлогом: to affect – влиять на to answer – отвечать на to influence – влиять на to follow – следовать за и др. переводятся глаголами в активном залоге или неопределенно-личной форме, причем соответствующий русский предлог ставится перед английским подлежащим.	The conditions of work are greatly affected by the government.	**На** условия работы сильно влияет правительство.

Неличные формы глагола
Инфинитив (Infinitive)

Инфинитив – основная форма глагола, от которой образуются все личные формы глагола во всех группах времен в действительном и страдательном залогах. Инфинитив, или неопределенная форма глагола, сочетает в себе свойства глагола и существительного.

Признаком инфинитива является частица "to". Она иногда опускается:

– после модальных и вспомогательных глаголов; must (can) produce; do not produce; Did the mill produce? Will produce и т. д.
– после глаголов физического восприятия: see, hear, feel, watch, notice в объектных инфинитивных оборотах и некоторых других случаях.

Инструкция 1

Повторите формы инфинитива:

Время	Active Voice	Passive Voice
Indefinite – выражает действие, одновременное с действием, выраженным глаголом-сказуемым	to produce	to be produced
Perfect – выражает действие, предшествовавшее действию, выраженному глаголом-сказуемым	to have produced	to have been produced
Continuous – длительный характер действия	to be producing	___
Perfect Continuous – действие началось в прошлом и все еще продолжается	to have been producing	___

Функции инфинитива

Инструкция 2

Помните, что инфинитив *в роли подлежащего* всегда стоит *перед сказуемым* (в начале предложения).
Переводится:

1) существительным;

2) неопределенной формой глагола.

Образец: *To know English* is necessary. – Необходимо *знать* английский. *Знание* английского необходимо.

Инструкция 3

Инфинитив в роли обстоятельства цели отвечает на вопрос «для чего?», «с какой целью?». Стоит либо в начале, перед подлежащим, либо в конце предложения. Может вводиться союзами *so as (to) – с тем, чтобы, in order (to) – для того чтобы.*
Переводится:

1) *неопределенной формой глагола с союзом «чтобы», «для того, чтобы»;*
2) *существительным с предлогом «для».*

Образец: *To know* English you should work hard. – *Чтобы знать* английский, вы должны много работать.

Инструкция 4

Инфинитив *в роли обстоятельства следствия* отвечает на вопрос «для чего?» и стоит после слов *too* – слишком, *enough, sufficiently* – достаточно, *sufficient* – достаточный, *very* – очень. *Переводится неопределенной формой глагола с союзом «(для того) чтобы».* Сказуемое при переводе часто имеет *оттенок возможности*.

Образец: 1) I am *too* tired *to go* to the exhibition – Я *слишком* устал, чтобы идти на выставку (чтобы я *мог* пойти…)

2) He is clever *enough to understand* it. – Он *достаточно* умен, чтобы (он *мог*) понять это.

Примечание

В английском языке слово "enough" всегда стоит после прилагательного, но перевод следует *начинать именно с "enough"*, а потом переводить прилагательное: strong enough – достаточно прочный; accurate enough – достаточно точный и т. д.

Инструкция 5

Обратите внимание на *инфинитив в роли определения. Он всегда стоит после определяемого существительного* и отвечает на вопрос «какой?». Инфинитив в роли определения чаще всего *имеет форму страдательного залога* и *переводится определительным придаточным предложением*, вводимым союзным словом *«который»*. Сказуемое русского предложения выражает *долженствование*, *будущее время* или *возможность.*

Образец:

1) The method *to be used – метод, который нужно (можно, будут) использовать.*
2) A beater roll breaks up the material *to be pulped*. – Барабан ролла измельчает сырье, *которое нужно* превратить в массу (*которое будет превращено в массу*).

Инструкция 6

Инфинитив – часть сказуемого. Инфинитив может быть частью: а) простого сказуемого; б) составного именного или в) составного модального сказуемого (=составного глагольного сказуемого) лишь в том случае, если ему предшествуют глаголы *to be, to have, модальный или вспомогательный глагол.*

Образец:

1) The purpose of the system *is to maximize* production. – Цель этой системы – максимально повысить производительность. Цель системы *состоит в том*, чтобы максимально… Целью системы *является* максимальное повышение…
2) The system *is (has) to maximize* production = The system *must (should) maximize* production. – Эта система должна максимально повысить производительность.

Таблица 2 – Причастие

<table>
<tr><td rowspan="2">Вид причастия</td><td colspan="3">Функция в предложении и перевод</td></tr>
<tr><td>часть сказуемого</td><td>определение</td><td>обстоятельство</td></tr>
<tr><td>1. Participle I
Active voice
selling
writing</td><td>He is selling his goods.
Он продает свои товары.

(Для образования времен группы Continuous. Самостоятельно не переводится).</td><td>The merchant selling his goods pays a profits tax.
Торговец, продающий свои товары, платит налог с прибыли.

The seller examined the letter containing an interesting offer.
Продавец изучил письмо, содержавшее интересное предложение.

(Причастие на -щий, -вший).</td><td>(When, while) selling his goods, the merchant pays a profits tax.
Продавая свои товары, торговец платит налог с прибыли.

(Деепричастие на -а, -я).</td></tr>
<tr><td>2. Participle I
Passive voice
being sold
being written</td><td>The goods are being sold.

Товары продаются.

(Для образования группы времен Continuous пассивного залога. Самостоятельно не переводится).</td><td>The goods being sold were foreign made.

Продаваемые товары были произведены за границей.

(Причастие на -емый, -имый).</td><td>(While) being moved the goods are insured against all risks.
Когда их перевозят (во время перевозки) товары страхуются против всех рисков.
(Придаточное обстоятельственное предложение; существительное с предлогом).</td></tr>
</table>

Окончание табл. 2

Вид причастия	Функция в предложении и перевод		
	часть сказуемого	определение	обстоятельство
3. Participle II Passive voice **sold** **written**	1) He **has sold** his goods. Он продал свои товары. (Для образования времен Perfect. Самостоятельно не переводится). 2) The goods **are sold.** Товары проданы. (Для образования пассивного залога. Самостоятельно не переводится).	The goods **sold** gave substantial profit. **Проданные** товары принесли существенную прибыль. The problem **discussed** yesterday is very important. Проблема, **обсуждавшаяся** вчера, очень важна. (Причастие на -щийся, -мый, -ный, -тый, -вшийся).	**If sold**, the goods will give substantial profit. **Если их продать**, товары принесут существенную прибыль. (Обстоятельственное придаточное предложение).
4. Perfect Participle active voice **having sold** **having written**	–	–	**Having sold** his goods he got substantial profits. **Продав** свои товары, он получил существенную прибыль. (Деепричастие на -ив, -ав).
5. Perfect Participle Passive voice **having been sold** **having been written**	–	–	**Having been sold**, the goods gave substantial profit. **После того как товары были проданы**, они принесли существенную прибыль. (Придаточное обстоятельственное предложение).

Таблица 3 – Герундий

Функция в предложении	Примеры	Перевод
1. Подлежащее	**Chartering** of ships is very important for shipments of goods.	**Фрахтование** кораблей (**фрахтовать** корабли) очень важно для перевозки товаров. (Инфинитив, существительное).
2. Часть сказуемого	The main task is **keeping** customer's accounts.	Главная задача – **хранение** счетов клиентов (**хранить** счета клиентов). (Существительное, инфинитив).
3. Прямое дополнение	The situation requires **controlling** the supply.	Ситуация требует **управлять** (**управления**) поставками. (Инфинитив, существительное).
4. Определение (обычно с предлогом **of, for** после существительного)	The ability **of influencing** the commerce is studied attentively.	Способность **влиять** (**влияния**) на торговлю изучается внимательно. (Существительное, инфинитив).
5. Обстоятельство (обычно с предлогами: **in – при, в то время как,** **on (upon) – по, после,** **after – после,** **before – перед,** **by – творит. падеж,** **instead of – вместо того чтобы,** **for – для** и т. д.	He is able to discuss the terms of an order **without receiving** our special authorization.	Он может обсуждать условия заказа **без получения** (**не получая**) нашего специального разрешения на это. (Существительное с предлогом, деепричастие с отрицанием).

ЧАСТЬ III. ЧТЕНИЕ НАУЧНЫХ СТАТЕЙ

Article 1

Task 1. Read the text below.

Domestic heating with compact combination hybrids (gas boiler and heat pump): A simple English stock model of different heating system scenarios (by George Bennett, Stephen Watson, Grant Wilson, Tadj Oreszczyn)

Abstract

The heat decarbonization challenge remains substantial, competing low carbon solutions such as hydrogen and heat pumps (HPs) and the entrenched position of gas combination boilers create inertia in many markets. Hybrid appliances which can directly replace gas boilers may provide a low disruption, low-cost pathway to net zero in gas-reliant markets. Emerging compact combination (CoCo) hybrid heating appliances which combine a gas combi boiler and a small HP unit in one appliance have been modelled for the English housing stock across a range of different scenarios. CoCo hybrids offer sizeable energy demand reduction of up to 60 % compared to current gas boilers, also reducing peak electrical demand by 10 GW compared to air source heat pumps. The control strategy for switching between HP and gas boiler is key in determining the scale of demand reduction. Modelling sensitivity to the HP size within CoCo hybrids showed that a 50 % reduction in energy demand compared to gas boilers could be achieved with a standard 2.5 kW HP. A lack of clarity in regulation and policy incentives for hybrids exists. To drive innovation and performance improvement, product regulation for hybrids needs to be improved to support decarbonization of heat with this promising technology.

Practical application

Convenient, low disruption heat decarbonization technology is crucial to the speed of deployment necessary to achieve net zero. This article defines the size of HP necessary to achieve rapid low disruption impact and distinguishes the types of compact hybrid which can deliver the highest decarbonization impact while minimizing in house disruption and the electrical grid impact.

Keywords

Low-carbon heating, stock modelling, heat pump, boiler, hybrid, heat decarbonization

Introduction

Domestic energy demand accounts for 29 % of the UK national total. Energy is used within the home primarily for space heating and gas boilers continue to dominate domestic heating in the UK making up the majority of the 22 million homes heated by fossil fuel boilers. Over 1.7 million boilers are being installed annually, both as replacement and in new build homes, further adding to the install base of fossil fuel burning heating systems which need to be decarbonised. Combination boilers are the most popular in the market accounting for 59 % of installed gas boilers.

Combination boilers provide both space heating and instant hot water production within one appliance with no need for a separate hot water tank. As such they are more compact, cheaper and quicker to install than traditional ‘system’ boilers with hot water tanks. Once installed in a home, ‘like for like’ replacement, either planned or part of a ‘distress purchase’ is simple and inexpensive. Instantaneous hot water is beneficial for energy efficiency in terms of avoiding heat loss from the storage tank, but inefficiencies of ‘combi loss’ and cycling due to the high outputs and limited modulation ranges can negatively impact the efficiency.

Electrification of heat is a key part of decarbonizing the built environment. The UK Government plans to eliminate fossil fuel gas connections from new buildings and the IEA is recommending that only hydrogen ready boilers are installed from 2025. Heat pumps play a central role in Government policy, aiming to increase the deployment of heat pumps (HPs) annually to 600,000 from 30,000 in 7 years. This is likely to be a more significant change to household heating than the introduction of gas central heating which took 40 years to grow from 25 % of homes in 1970 to over 90 % by 2010. This shift to electrically driven heating will impact life within the home and the whole energy system.

Utilizing gas boilers for space heating and instantaneous hot water places considerable demand on the gas network to supply energy when required for combustion and heat. The concentration in demand from channeling cyclical heat demand onto the gas network results in large variations of demand across the seasons and diurnally. Research into the scale of the heat demand, as embodied in the network gas demand, has led a number of researchers to estimate the current demand and model the impact of future electrification of heat on the electricity grid. The scale of current gas heat demand has been estimated as being of the order of 170 GW of peak demand building on the work of Wilson on daily gas demand and utilizing demand data from 8700 dwellings. Monitoring of real gas demand shows peaks of up to 214 GW in the gas network during cold weather periods. There remains uncertainty in the estimation of the gas heat peak demand with alternative models based on a UK heat demand model using a regression model of GB gas demand merged with daily empirical heating profiles. Such a model yielded 277 GW peak domestic heating demand. The uncertainty of heat demand is critical in light of the general acceptance that significant electrification of heat will be necessary although the scale remains uncertain.

A radical and rapid increase in the electrification of heat poses considerable risks to the decarbonization of electricity. Currently, two factors contribute to decarbonization: the reduction in electricity demand plus the deployment of renewable generation, in particular offshore wind. The steady decarbonization of electricity in the UK could be reversed if the increase in demand from the install Faculty of the Built Environment, The Bartlett School of Environment, Energy and Resources, Energy Institute, generation. The risk of electrifying heat too quickly is increased utilization of gas power generation making it cheaper and more carbon efficient to deploy gas boilers than gas-fired electricity generation.

Besides the unknown scale of grid improvements necessary to electrify heat at a local level, other factors affect the decarbonization pathway of domestic heat. The dominance of gas boilers in homes is one aspect of a wider uniformity to the heating sector with far reaching implications for a transition to low carbon heat. Appliance manufacture and supply, installation workforce and customer expectations have developed around the gas boiler, embedding it as the default. The workforce is especially aligned with the technology, with over 100,000 installers active in the UK for fitting and servicing boilers, compared to approximately 1000 heat pump installers.

Conversion of combi boiler heating systems to electric heat pump systems is a relatively costly and disruptive transition. Additional insulation on the building fabric, hot water storage and low temperature heat emitters are some of the aspects which need to be considered. Crucially, the installation requires additional certification of an installer instead of, or in addition to, the current industry standard accreditation for gas boiler fitting, GasSafe membership. Once installed, the heat pump may also need to be operated continuously to operate efficiently, a culture change in UK home heating.

The Committee on Climate Change has recommended that, given the rapidity of the change needed in the heating sector and the uncertainty around electricity grid impact, that hybrid heating appliances should be rapidly deployed at scale to homes on the gas grid with an aim to having up to 10 million appliances installed by 2035. A hybrid heating system is one that combines a gas boiler and heat pump in one heating system. The HP can be added to the existing boiler system allowing for the boiler to provide ‘peaking’ service when a higher power output is required such as when fast warm up or higher temperatures are required in the radiators on colder days. The hybrid is typically suggested as a suitable solution to address two potential issues. Local electrical network grid capacity problems caused by simultaneous use of multiple heat pumps which could be mitigated by the use of hybrids as switching hybrid heating systems from electricity to gas at certain times would help to avoid costly network upgrades. Costly and disruptive aspects of HP installation can also be averted with hybrid systems, such as the upgrading of radiators or the installation of a hot water tank. This is seen as a ‘low regrets’ policy moves due to the preservation of multiple decarbonization options the future including, district heating, fully electric heating and hydrogen-based heating pathways.

However, most hybrid systems such as those trailed in the Freedom Project are essentially two heating systems in parallel with a central controller; this is more akin to a bivalent heating system than the integrated petrol/electric hybrid systems in transport vehicles. Bivalent systems with active secondary heat sources (HPs, biomass burners rather than passive solar thermal) have cost and space implications due to the redundancy built in and the lack of integration. The complexity of this type of bivalent boiler/HP system presents a challenge to occupants and heating professionals which can be exacerbated when incompatible equipment from multiple manufacturers is installed. For occupants, understanding what the system is doing at any given time can be challenging, or for heating engineers to find faults or commission multiple units. Utilizing two heat sources to heat the home presents a control and optimization challenge. Although a hybrid heating system has two distinct heat sources, generally they both serve the same heat emitter system; therefore, the control systems must balance efficiency optimization with predictable and desirable heat provision through appropriate heat emitter temperatures and flow rates. This can lead to complex hydraulic configurations and control algorithms. For example, the HP and boiler could operate hydraulically in parallel or series and the control algorithm can be programmed to avoid HP operation under certain outdoor temperatures or central heating flow temperatures. Keeping cost, complexity and disruption to a minimum could prove critical in kickstarting the shift to low carbon heat given the current convenience and familiarity of gas combi boilers.

By reducing the thermal output and size of the heat pump, manufacturers have developed appliances which combine a boiler and air source heat pump in one unit. The compact combination hybrid (CoCo hybrid) is a technology which could offer the consumer a relatively cost-effective appliance which can be installed by the current cohort of boiler installers as the HP is a sealed unit internal to the appliance only. By placing the HP and boiler in one unit, some benefits can be realized over a traditional hybrid. The HP can scavenge waste heat from the boiler in addition to the normal outside air, the control system can be optimized to the characteristics of the appliance components rather than being generalized and both manufacturing and installation costs can be reduced compared to traditional hybrids. The boiler part of the CoCo hybrid like the standard boilers used in standalone or traditional hybrid systems can be made to be 'hydrogen ready' so as not to lock in extended natural gas dependency. The compromise of the system is that the HP is typically smaller than required to heat the home solely. However, the discrepancy between the high instantaneous power demand for hot water (~20–30 kW and space heating (~1–15 kW) which causes inefficiencies in the current boiler fleet can prove to be advantageous for the CoCo hybrid where the hot water can be heated only by the boiler and space heating by both the HP and the boiler with the higher efficiency HP taking over the heating load at the low heat demand levels (and mild outdoor temperatures) which force boiler cycling inefficiency. It is worth noting that the requirement for instantaneous water heating, as opposed to stored hot water, has driven the large boiler sizes common today. Using hot water storage would reduce this requirement and reduce the negative impacts of boiler cycling on efficiency. However, 2 million hot water stores have been removed from UK homes and 4 million additional combination boiler systems installed in the last 10 years and occupants may be reluctant to lose the space they have recently gained. Although advances are being made in the area of thermal storage to add value both to the consumer and the wider energy network, smart thermal stores can monitor energy prices to reduce running costs and phase change materials are being used to reduce the size of thermal stores. This research endeavors to understand to what extent the modest size of the HP within a CoCo hybrid could deliver carbon savings of HP heating while mitigating the necessity for widescale grid reinforcement during a transition.

Methodology

The impact of the choice of heating systems manifests itself in many ways across society, through investment capital spend, disruption to homes, household energy bills, grid demand of the electrical and gas networks and more. This research focusses on a sub-section of this complex system landscape. The parameters and relationships of interest in this research are modelled with different heating system types/sizes and control methodologies to map the boundaries of how CoCo hybrid heating can impact the home heating sector in comparison to both the incumbent technology (gas boilers) and the leading low carbon technology (heat pumps). The five indicators of performance used in this article are as follows:

– Peak electricity/gas demand as a function of outdoor temperature,
– load duration curves for electricity and gas under standard climatic conditions,
– energy demand,
– energy bills and
– domestic heating CO_2 emissions.

In order to derive these indicators, an hourly bin model was constructed in Microsoft Excel. The schematic representation of the model is shown in Fig. 1.

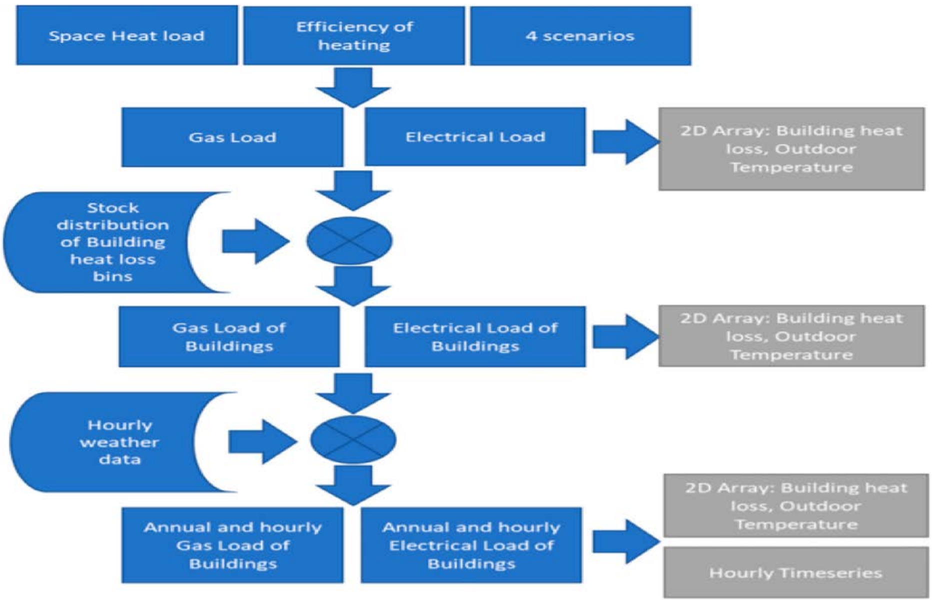

Figure 1. Flow diagram of information within the CoCo hybrid stock model

The model foundation is a 2D array of building heat loss (100 W/K resolution) and outdoor temperature bins (1°C resolution) which is used to calculate the steady-state heating demand for each heat loss intersection of building heat loss across the outdoor temperature spectrum with constant internal temperature, accounting for fixed internal (metabolic, cooking, appliances, etc.) and solar gains. Maintaining incidental gains at a fixed level is a simplification which borrows partly from the SAP monthly methodology which takes such gains as being constant over each month. Solar gains were assumed constant to simplify the modelling. The focus of the model is on the comparative impact of heating systems, which have been shown to be the critical parameter in sensitivity analysis of building stock models.

Capturing how a heating appliance reacts and responds to changes in operating conditions is a product of basic thermodynamics, appliance design and control logic. The heating appliance must meet the heating system demand which is driven by occupant comfort, external weather and the building heat loss. The energy required to meet the demand can depend on the hydraulic temperatures/flow rates and outdoor air temperature.

Table 1 – Description of modelled scenarios

Scenario	Heating system	Description and control
Scenario 1	Gas boiler	Modern condensing gas combination boiler
Scenario 2	CoCo hybrid	Control logic: HP will be ON if outside temperature is above 5°C and demand power is within HP range and OFF otherwise
Scenario 3	CoCo hybrid	Control logic: HP will be ON when HP power is within range and OFF otherwise
Scenario 4	CoCo hybrid	Control logic: With HP priority at all times (continuous HP operation), boiler provides remaining heat demand
Scenario 5	ASHP	Full heat pump system with variable COP

Certain features were chosen to remain constant across all appliance scenarios, such as the relationship of heat pump and outdoor air temperature. The extent of hydraulic configurations and control strategies which are possible for a hybrid is considerable. Control algorithms of heating systems, both boilers and HPs, and therefore emerging hybrid systems are also a matter of commercially sensitivity and rarely in the public realm. However, this article seeks to determine the sensitivity to different control strategies on peak power demand, total energy and carbon emissions. Five heating system scenarios were implemented in the model to convert the building heating load into gas and/or electricity demand. Scenario 1 represents the current status quo of near universal use of gas boilers for heating. Scenario 5 just air source heat pumps (ASHPs) presents a possible future heating landscape to meet net zero. Scenarios 2–4 explore a CoCo hybrid consisting of a 28 kW heat output gas boiler plus 4 kW heat output ASHP with three different control scenarios. Scenarios 2–4 could play a role in transitioning from Scenario 1 to 5. The descriptions of the scenarios are explained in Table 1.

Table 2 – Heating technology efficiency assumptions

Technology	Efficiency profile
Boiler	Modern condensing gas combination boiler where efficiency is highest (92 %) when demand power is within the modulation range of the boiler. Boiler cycling reduces the boiler efficiency (80 %) when heating demand is below the range of modulation.
Air source heat pump	Coefficient of performance varies linearly with outdoor air temperature. Model is a synergy of RHPP (anchoring at COP of 2.4 at 10 °C) and published manufacturer data COP at 25 °C is 2.7
CoCo hybrid	COP at 5 °C is 2.14 Boiler has fixed efficiency and HP efficiency as per individual technologies (above), no interaction assumed which would affect efficiency.

The efficiency of the appliances modelled in the scenarios followed the logic outlined in Table 2. The model assumes a distribution of heat loss in the English housing stock equivalent to what was measured as part of the 2011 English Housing survey and reported in the Cambridge Housing Model. Scaling the gas and electrical demand according to this distribution using the appliance definitions from Table 1 gives the stock level array of energy demand (split by gas and electricity) to heat the English housing stock as a function of external temperature. Mean internal temperature was assumed to be constant at 19 °C to account for the simplicity of the model not implementing a bi-modal heating profile but representing expected mean temperatures in homes.

Taking this distribution and combining it with a representative weather profile from ASHRAE's International Weather for Energy Calculations (IWEC) project (location: Finningley UK, based on the period 1982–1999) gives the hour by hour heat load on the gas and electricity networks for the different scenarios. Using an hourly model with continuous 24 h heating of the buildings makes two simplifications which counteract each other. Modelling with hourly weather data will overestimate the heat load on the building due to the omission of the temperature dampening effect of the building thermal mass. However, the continuous heating profile, as mentioned earlier, smooths heating up peaks of demand when the heating schedule starts, and extra power is needed to quickly raise the internal temperature; as mentioned earlier, the mean internal temperature was chosen to account for the difference between set point temperatures and cooling down periods.

Modelled results and discussion

Plotting the total heating demand against outdoor temperature (before the addition of the weather profile), Fig. 2 shows the scale of peak heating demand reduction potential during colder periods and the scale of power availability requirement needed to satisfy the steady-state heat demand. Throughout this analysis, 'power' is defined as the input power to the heating system (as would be measured by the gas or electric metre) for the purpose of conversion to space heating rather than delivered heat. The different hybrid systems modelled (Scenarios 2–4) perform differently with up to two times the power required for Scenario 2 compared to 4, and the difference is greatest at temperatures below 4 °C. This stage of the model demonstrates the potential of heat pumps in the building stock to alleviate load demand on the whole energy system as well as the electrical grid at periods of high heat demand. The complete conversion of heating systems to air source heat pumps, as per Scenario 5, indicates over 100 GWof peak heating power reduction (electricity and gas combined) in sub-zero weather conditions (Fig. 2). However, this steady-state modelling overlooks start up and heat up loads which would be higher in all cases unless heating was continuous. However, since the gas and electricity networks operate differently with regard to provision of peak loads (line pack for gas and peaking plant for electricity), it is necessary to look deeper at the split between gas and electricity power profiles. Also, this input power demand is just for providing space heating, not for hot water demand which currently drives the sizing of combi boilers.

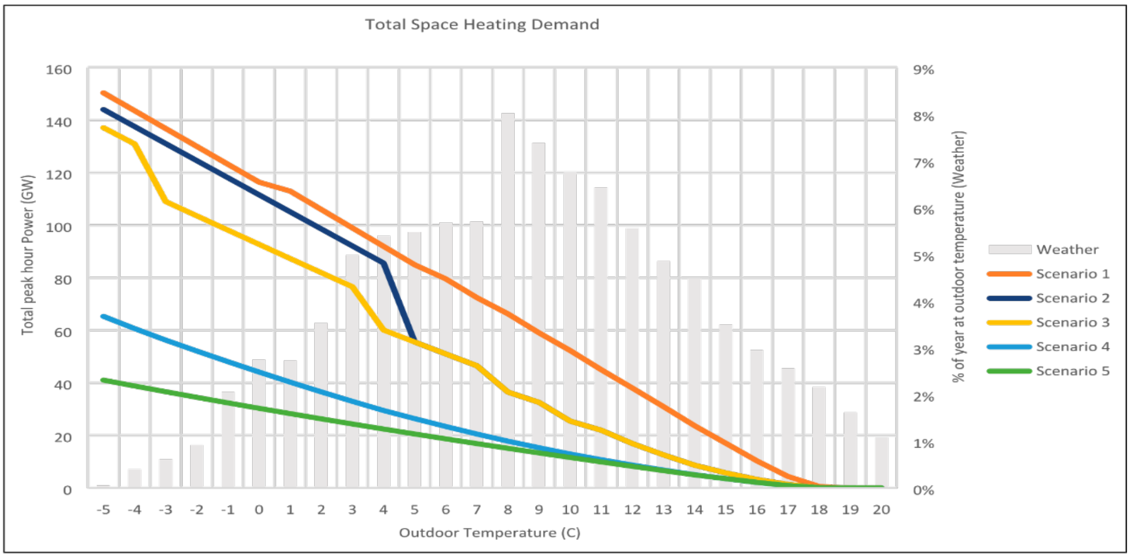

Figure 2. Total space heating energy demand as a function of outdoor temperature Hybrid HP size 4 kW

The space heat energy demand was modelled on a disaggregated basis across the two modelled energy vectors, gas and electricity. Scenario 1, representing the incumbent dominant boiler technology, is limited to gas only and displays the highest input energy demand across all temperatures due to the fundamentally lower, and limited, boiler system efficiency. The demand is approximately representative of the underlying building heat demand before heating efficiency since the boiler efficiency approximates 90 % across the model. Scenarios 2, 3 and 4 are compact hybrids, in this baseline case with a HP size of 4 kW. The impact of varying the CoCo hybrid HP size will be explored later in the article. The difference in peak demand between Scenarios 2, 3 and 4 stems not from the physical dimensions or thermal output of the CoCo hybrid (which are constant) but solely on the control methodology implemented.

While all CoCo scenarios offer lower overall power demand across the temperature spectrum, the temperature-based control strategy of Scenario 2 which operates the HP only above 5 °C shows the lowest potential to reduce peak demand at low temperatures but above 5 °C where the HP can operate freely and the building heat loads are lower across the stock giving the HP part of the CoCo hybrid a greater role. At these higher ambient temperatures, demand is significantly lower.

Removing the outdoor temperature limit of the HP (set at 5 °C), as in scenario 3, but still implementing a reduction to COP with outdoor air temperature, improves the performance and lowers the overall heat energy demand at lower temperatures. However, the 'either/or' control strategy which precludes running the HP and boiler simultaneously in Scenarios 2 and 3 limits the overall reduction in input power demand. Scenario 4 is based on a control strategy where the HP is used whenever possible and the input power demand is supplemented with the boiler to satisfy the current heat need. This greatly increases the proportion of heating provided by the HP which improves the efficiency thereby lowering the demand.

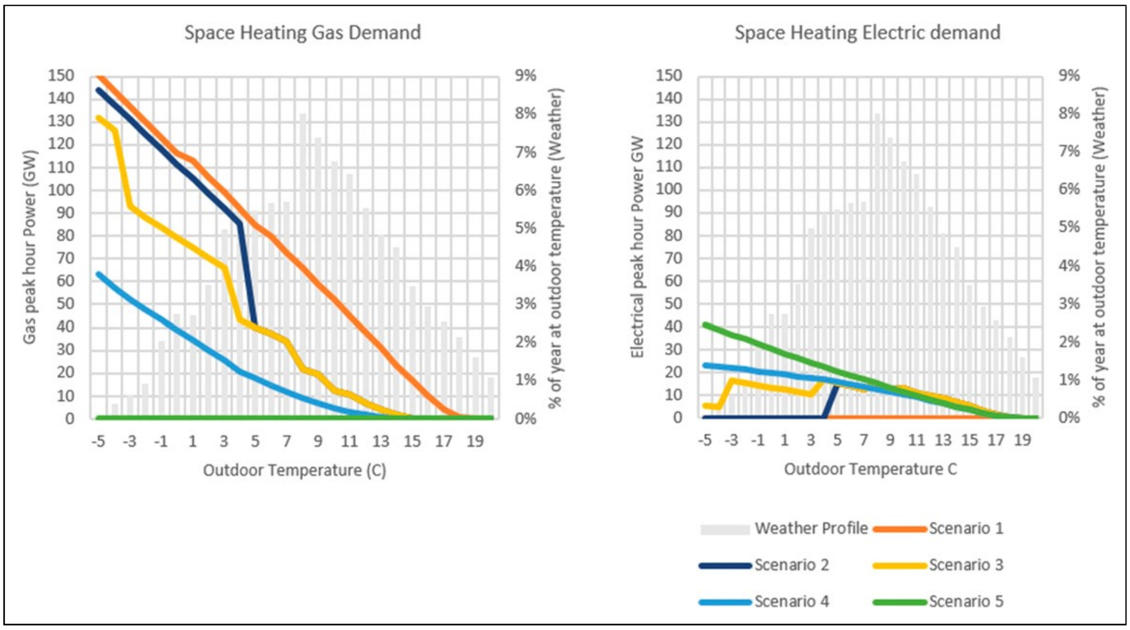

Figure 3. Space heating energy demand, gas and electricity as a function of outdoor temperature. Hybrid HP size 4 kW

Analyzing the split of gas and electricity demand underlying the scenarios (Fig. 3) gives greater insight into the operation of the CoCo hybrids across the English housing stock, highlighting the sharp drop in HP contribution from the CoCo in Scenario 2. There is a similar electrical demand across all scenarios (except Scenario 1: boiler) at milder air temperatures [for reference, the long-term average UK outdoor temperature during the October to March heating season is 6.35 °C (1981–2010) and increasing at approximately 0.22 °C per year since 1970] as the control algorithms converge into 100 % HP operation over a lower building stock heat demand. This is interesting in the context of the implication of aggressive building heat demand reduction through fabric measures (the so-called fabric first strategy) which would shift the heat demand into this area even at lower outdoor temperatures, reducing the need for hybrid appliances. In the absence of large reductions in building heat demand, which has been shown to pose its own problems of cost and embodied carbon payback, it is therefore reasonable to assume that demand reduction through heating efficiency will need to deliver significant proportion of the emissions reduction. The next stage of modelling takes the temperature dependent heating profile of the English housing stock and calculates the time series energy demand profile across a full year. To achieve this, the complete stock was modelled at a representative location for England. A central weather profile was chosen for the modelling, centered on the Finningley location and using weather data from the US Department of Energy, also utilized in the commonly used Energy Plus modelling environment.

For the purposes of this analysis, all homes were assumed to be heated constantly. This is a departure from the known bi-modal heating schedule commonly seen in the UK and formalized in the UK's Standard Assessment Procedure (SAP). However, the shift to continuous heating profiles is integrated in SAP to accommodate smaller output heating systems with smaller plant size ratios (PSRs). The PSR is a measure of the ratio of the heating system thermal output to the building heat load. A smaller PSR limits the heating ramp rate of the heating system and therefore the viability of the bi-modal heating, requiring continuous heating schedules. This is a separate effect from the reduction of flow temperatures, either in a boiler or HP system, which will benefit efficiency but also reduce the thermal output of the existing emitters in retrofit cases, limiting heating up times and also the steady-state thermal output, probably requiring upgrades to the emitters. The benefit of a lower PSR and longer heating schedule is lower capital expenditure for the heating system and heat emitters and higher efficiency during operation. The higher efficiency can significantly outweigh the longer operating times resulting in both higher thermal comfort and lower running costs both for boilers and heat pumps. The internal set point temperature was initially chosen to be representative of the mean internal temperature rather than a thermostat set point. This is a significant simplification in the modelling and reduces the complexity of heating schedule occupant behavior and heating system response to a single parameter. Internal temperature levels and profiles are ongoing areas of research. It is recognized that more detailed, higher temporal resolution, dynamic building simulation models may offer more detail to explore temporal and geographic variation in internal set point, and for the purposes of this analysis, a uniform temperature was considered sufficient. After calculating the hourly power needed to satisfy the building stock space heating demand over the complete simulated year, the load duration curve of the gas and electricity demand is plotted to (Fig. 4) explore what the scale of gas and electrical supply would need to be in a typical year.

The impact on the load duration curves is most notable in the shape of the gas load over the year, where Scenarios 3 and 4 reduce both the total gas demand and also the peak demand. The simplest CoCo heating control strategy in Scenario 2 does reduce gas consumption but has little impact on the peak demand due to the shutting off of the HP at lower temperatures. The electricity load duration curve shows the significant impact that the hybrid control strategy can play on peak electrical demand, with the impact that it can therefore have on total generation capacity. Compared to the estimated peak of over 40 GW for when heating all homes with ASHP in Scenario 5, the CoCo hybrid scenarios reduce that peak to 30 GW for Scenario 4 and between 20 and 30 GW for the other hybrid scenario. The load distribution curves presented in Fig. 4 are based on the heating system's internal control algorithms which are modelled to respond to a combination of building heat demand and outdoor temperature. However, with the introduction of internet-connected heating appliances, there is the opportunity for an individual heating system to respond to price signals or to remotely control groups of heating systems to the benefit of the wider energy system. The ability of a hybrid to provide Demand Side Response (DSR) services through switching from HP to boiler, that is, electricity to gas, at times of low availability of renewable electricity or high electricity cost, is an aspect of hybrids which could prove useful as the proportion of renewables increases through allowing grid operators or DSR aggregators limited control of the operation of a hybrid. This would change the shapes of the load duration curves in such a way to reduce the use of electricity, but the limits of the switching capacity of the building stock would be greater for the scenarios with higher proportions of HP usage.

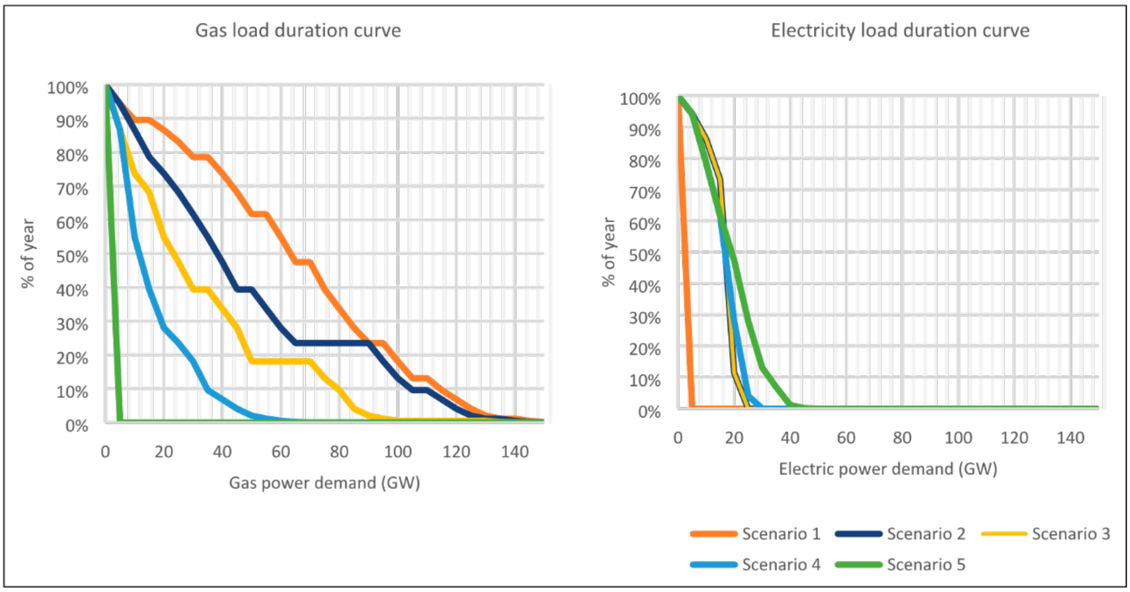

Figure 4. Load duration curve for gas and electricity

Peak demand is an important criterion for the transition of heating from gas to electricity and heat pumps but needs to be balanced against the cost, energy demand and carbon emissions associated with the split of gas and electrical energy used in heat generation.

In Fig. 5, the total modelled space heating demand across the 5 scenarios can be seen. The impact of the high efficiency of ASHPs increases as the proportion of heat provided by the HP increases up to the maximum in Scenario 5. It is striking that although the heating appliance capacity and thermal output is constant across Scenarios 2–4, the input energy demand is more than halved. Scenario 4 most closely follows the gas/electricity split of 50:50 which is assumed in the Standard Assessment Procedure. The variation in the distribution of heat demand to the boiler or HP within the hybrid is important to recognize as the control algorithms for heating appliances are generally not captured in the appliance testing methods which test the boiler and HP separately, combining the resulting efficiencies in a standard ratio, as happens in SAP at the level of 50:50.

The variation in energy savings relative to the gas boiler-based Scenario 1 is considerable going from 16 % up to 62 % (Table 3). This range of savings shows two aspects of the role of hybrids: that the control algorithm plays a key role in the performance (control strategy accounts for all the variation in the modelled savings) and that the potential savings when HP operation is optimised in the hybrid can rival that of the full HP scenario. Scenario 4 has a 4 kW HP unit in the CoCo hybrid, regardless of building space heat demand and gives a potential 62 % energy saving, whereas the full HP systems in Scenario 5 demonstrate a 76 % saving.

Table 3 – Space heating energy demand and savings

Scenario	Gas demand (GWh)	Electricity demand (GWh)	Total (GWh)	Relative saving to Scenario 1
1	522,250	—	522,250	—
2	372,950	66,674	439,624	16 %
3	240,337	93,063	333,401	36 %
4	101,906	97,271	199,176	62 %
5	—	124,171	124,171	76 %

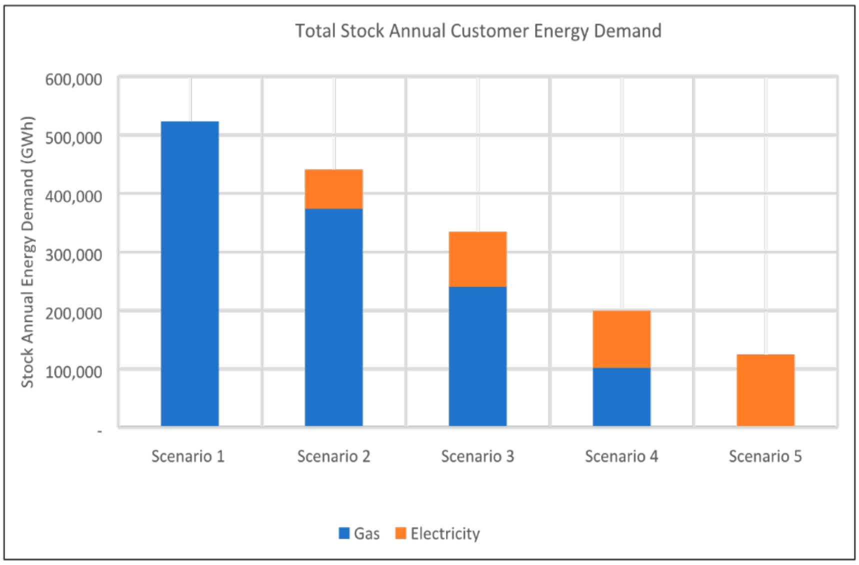

Figure 5. Stock annual input energy demand

The predicted emissions from the modelled scenarios (Fig. 6) depend strongly on the assumptions of the emission intensity of the electricity grid; three different emission factors are explored in this article. The emissions factors from SAP (SAP 2012 519 gCO2/kWh and SAP10 233 gCO2/kWh) were used since it is the most widespread building modelling tool in the UK used across millions of homes for Energy Performance Certificates.

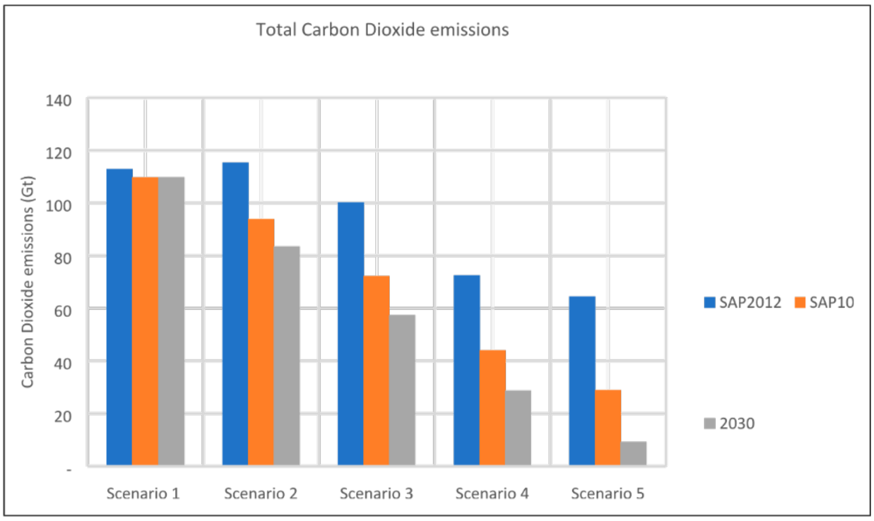

Figure 6. Stock annual emissions of carbon dioxide

Also, an estimate of the grid intensity in 2030 was taken from the National Grid Future Energy Scenarios 2020, 'System Transformation' scenario (75 gCO2/kWh). Note that more ambitious scenarios of carbon intensity reduction have also been modelled by the National Grid including zero carbon electricity by 2030. With the exception of Scenario 2 with SAP 2012 intensity factors, all CoCo hybrid scenarios present significant reductions in carbon emissions from heating. The considerable carbon emission impact of both HPs and hybrids can be seen with a potential 60 % reduction in emissions for the best performing hybrid (SAP10 factors), but caution should also be exercised as the worst performing hybrid in Scenario 2 only delivers 15 % carbon savings. Modelling carbon emission factors for radical changes to heating in homes is complicated by the feedback effect that any major electrification of heat will cause. The rapid decarbonization of the grid through increased proportion of renewables may be reversed as the demand grows, possibly causing increased reliance on gas fired electricity generation, therefore shifting the carbon balance back in favor of combustion of gas at the home directly for heat.

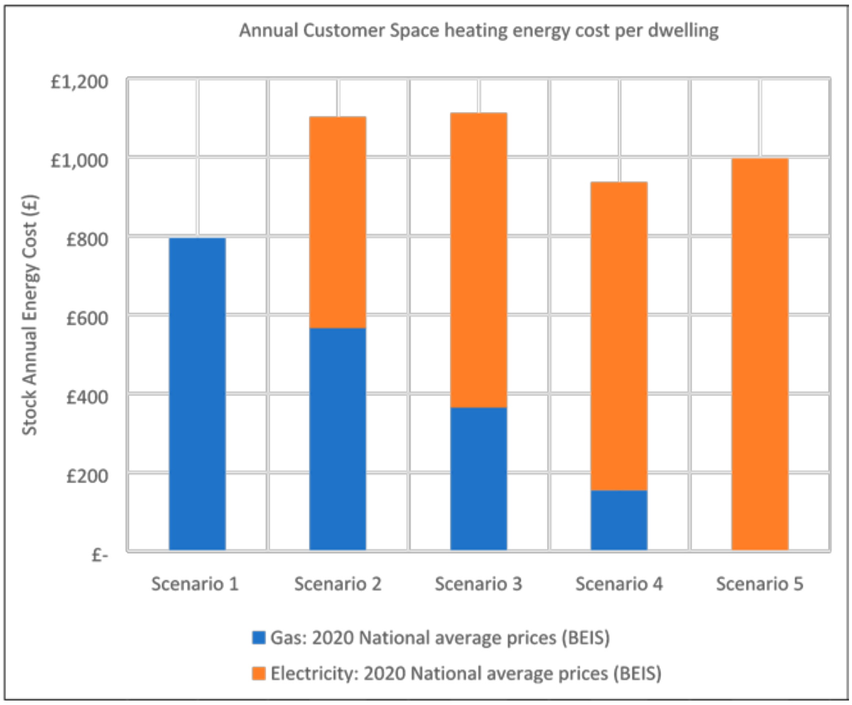

Figure 7. Estimated annual energy costs for customers per dwelling

Energy costs play a key role in the consumption of energy for heat. Modelling future gas and electricity prices is beyond the scope of this research. The role of government policy governing where environmental and social obligation costs are levied and how they change over time plays a large role in the absolute and relative costs of gas and electricity. A significant part of the higher costs of electricity lies in the 22.9 % obligation costs compared with just 1.9 % for gas. Competition between energy suppliers is a well-established feature of the UK energy market, presenting the consumer with considerable variation in energy prices driving around 400k consumers switching supplier per month. Taking a snapshot of how the modelled scenarios would affect average dwelling energy bills is presented in Fig. 7. The costs presented represent only the space heating portion of domestic energy use and are calculated using the mean unit cost of gas and electricity per kWh without fixed and standing charges of 3.3 p/kWh for gas and 17.4 p/ kWh for electricity. Viewing the impact of the modelled hybrids and ASHP through the lens of energy bills, the impact is negative, with no financial incentive to drive a shift from gas boilers. This highlights the distortion of energy prices with respect to both energy demand and carbon emissions both of which would benefit from the modelled heating systems, even in the case of the crude CoCo hybrid in Scenario 2. The decline in total energy demand seen in Fig. 5 is distorted by the electricity price driving bills up when the proportion of heat produced by the HP is increased. The modest differences in electricity demand between Scenarios 2 and 5 are amplified by the cost factor; Scenario 3 has the highest costs due to the relatively crude HP/boiler switching resulting in a similar electricity demand as Scenario 4 but without the corresponding drop in gas demand.

Sensitivity analysis

Comparing scenarios of CoCo hybrid heat provision on a national scale with both incumbent boilers and a full HP scenario has allowed for the exploration of differing control strategies of hybrid, operating the boiler and HP according to different rules and inputs. So far these CoCo scenarios have been based on the same fundamental physical CoCo hybrid specification. The boiler was sized above the maximum building heat load (28 kW) with a fixed minimum output of 5 kW, typical of combination boilers in the UK[44] and the HP was sized at 4 kW. A key feature of the CoCo hybrid concept is that the HP is contained wholly within the appliance casing, therefore minimizing the space taken by the HP and contributing to making the whole appliance more comparable to the existing boilers which they could replace. A sensitivity analysis was performed on the model varying the HP size of the CoCo appliances from a minimum of 0.5 kW up to the level of standalone HPs, 8 kW. The boiler output size was maintained at 5–28 kW, typical of UK combi boilers.

In Fig. 8, the variation in modelled peak electrical space heating demand for the reference year is shown. The ASHP Scenario 5 is shown as 41 GW across all CoCo hybrid HP sizes for comparison. None of the CoCo scenarios reach the levels of the full HP scenario reflecting the continued contribution of boilers in hybrid systems even when the HP is theoretically capable of providing all the heat, but the boiler helps at lower temperatures.

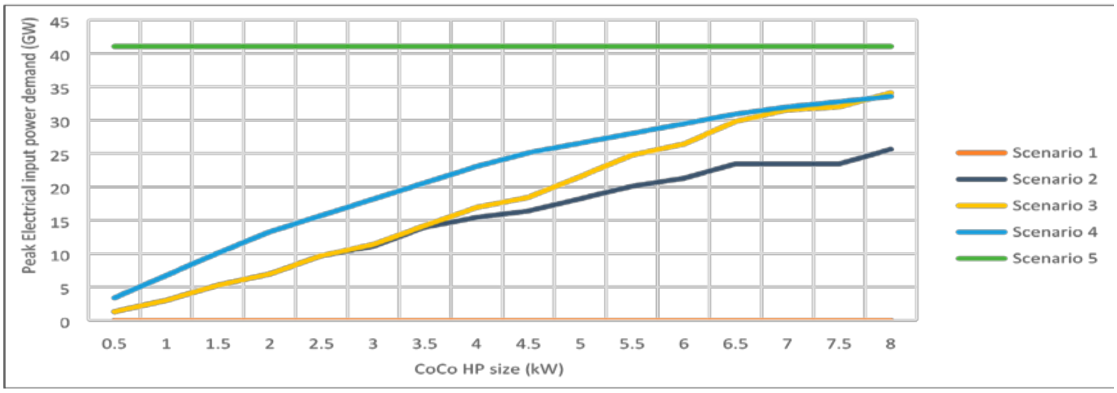

Figure 8. Peak electrical energy demand for varying CoCo HP size

The total modelled energy demand (gas and electricity) is shown in Fig. 9. Here, the differences between the CoCo control strategies are stark; the temperature limited HP operation of Scenario 2 limiting the HP contribution and therefore energy demand reduction, regardless of the HP size. Scenario 4 shows parameters of Scenario 3 CoCo hybrids would require the greatest energy demand reduction, relative to gas HP size of 6.5 kW to achieve the same 50 % reduction. boilers, with a 50 % reduction with the more modestly Energy bill cost (Fig. 10), estimated at today's sized 2.5 kW HP. The more restrictive operating prices as before, again highlights the price disparity that undermines using electricity for heating, despite the energy savings demonstrated the incurred cost is opposite. The larger HP sizes lead to rapid increases in billed energy cost; the case in Scenario 3 is such that the cost exceeds the fully electrified cost of ASHPs.

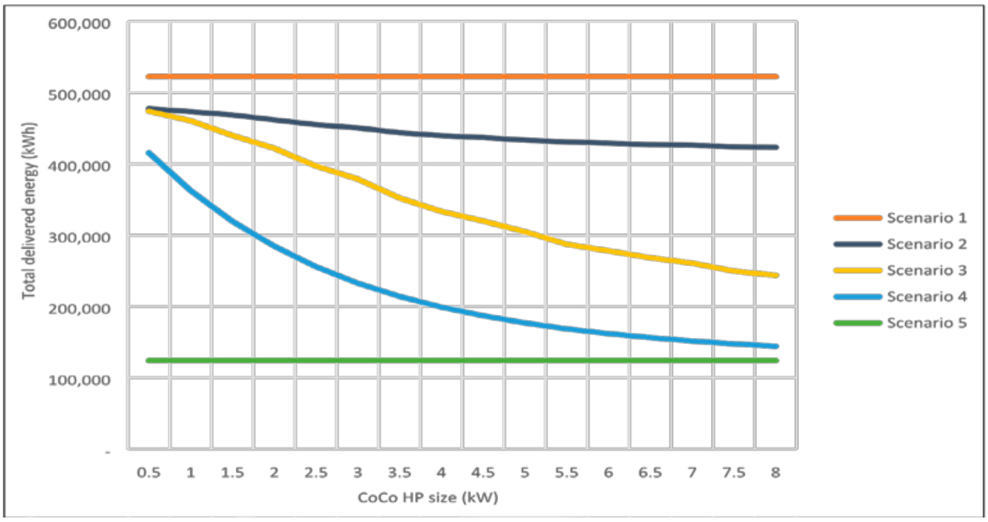

Figure 9. Total input energy demand for space heating (gas and electricity)

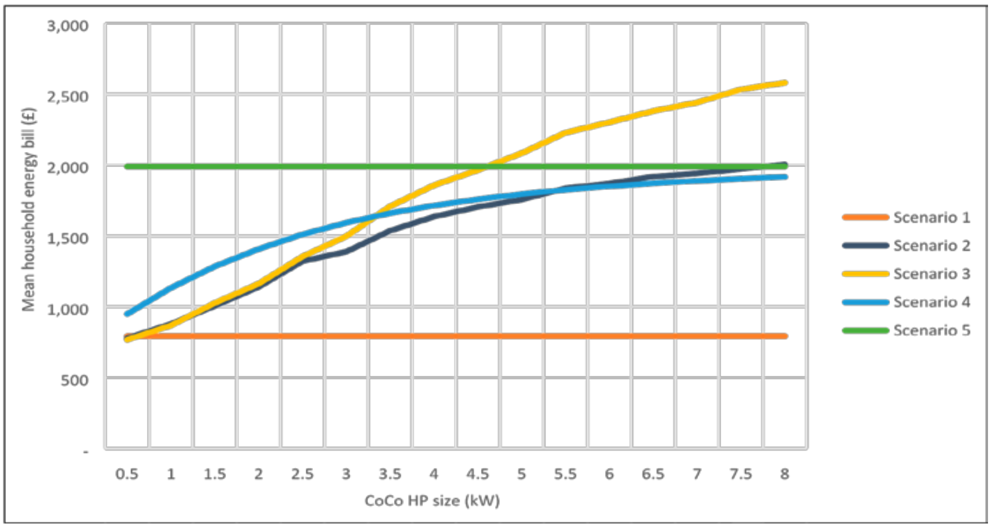

Figure 10. Modelled space heat energy cost across different hybrid HP sizes

Conclusions and implications

Existing English and UK space heating demand is highly seasonal and variable over a day. The swings in demand that space heating places on the wider energy system are buffered by the gas grid through its use of linepack.[4] The dominance of gas central heating and combination boilers allows for high levels of heating demand without outages or swings in energy cost to the consumer. In order to reach net zero, high levels of electrification of heat through heat pumps is foreseen. The risks to the energy system of high peak demands on the electricity grid are prompting policy makers to assess the role of hybrid heating. The compact combination hybrid appliances seek to provide a way to alleviate the impact of electrification of heating on the grid, while also providing a relatively compact appliance with reasonable up-front capital investment costs. By modelling a full transition of the English domestic building stock from gas boilers to CoCo hybrids, the limit case of impact can be seen. The CoCo control strategy is of key importance as it determines the proportion of heat generated by the higher efficiency ASHP within a hybrid. This has implications for the policy governing product standards and the methodology behind the UK's Energy Performance Certificate. It is clear from the modelling that not all hybrids are created equal and that a standard of specific performance testing should be developed to reflect the role of control algorithms in heating system performance. Energy demand and carbon emissions vary significantly across the modelled scenarios which maintain a constant heating system configuration for the hybrid models, but vary only the control strategy. The diminishing relative reduction in energy demand as the HP size of a CoCo hybrid increases shows that significant decarbonization of heat could be made with relatively modest HPs within the CoCo package. With a 2.5 kW HP within the CoCo hybrid, a 50 % reduction of energy demand at the national stock level is possible, if the HP use is not limited. The variability of demand across different hybrids (control strategy and specification) means that the simple split of heat demand 50:50 between the boiler and HP in any hybrid system forms part of the Standard Assessment Procedure used for EPCs and is inadequately flexible to account for variation in hybrid performance. It is likely that this conclusion holds as much for hybrids as for other hybridized or complex heating systems, which are likely to become more widespread in the future. Cost of energy has been shown to play a key and contradictory role in a shift to hybrid heating technologies. The cost of electricity does not reflect the underlying carbon intensity, even at 2020 levels and prices.

The incentive shown in terms of energy and carbon emission reduction across all CoCo hybrids is in contrast to increased energy bills, thereby disincentivizing the consumer to make the switch. Without addressing the retail energy price's masking of carbon intensity of energy, the role of hybrids or heat electrification is likely to be minimal. A full deployment of hybrids in the housing stock is not anticipated as a practical scenario for heat decarbonization; the modelling presented is envisaged as demonstrating a limit case, whereas, in line with CCC recommendations, the heating mix is likely to be more complex, with full HP systems being preferable where cost and grid constraints allow. Similarly, the deployment of hybrids, CoCo or otherwise, is likely to be sensible in areas where the conversion of the local gas grid to hydrogen is planned, which is unlikely to be widespread or uniform across the country. The modelling presented is limited by the exclusion of hot water production which is assumed to be 100 % heated by the boiler component of the hybrid. Although building heat load seasonality and diurnal variability could be simplified in the model sufficiently to generate useful results, the lack of high-quality data in hot water demand levels and diversity prevented satisfactory inclusion at this stage. Further work is planned to collect high frequency hot water consumption data which will form the basis of a supplementary hot water element to the hybrid model presented here.

A key finding of the research is the importance of the hybrid control strategy. In the modelled scenarios, the hardware component specifications in terms of kW output of boiler and HP parts of the hybrid were kept constant across scenarios. But the difference in control played a significant role in the split of energy demand between boiler and HP within the hybrid and therefore the savings relative to boilers. Hybrids cannot be assumed to be homogeneous in their performance or decarbonization potential. This has implications both for the policy governing hybrids which would need to account, either explicitly in definition or in performance testing, for the range of hybrid performance due to control and boiler/HP specifications. The potential for CoCo hybrids, if designed and developed optimally for energy demand reduction, is significant but needs careful consideration in policy, both in terms of hybrid product regulation and also the wider context of differences in gas and electricity prices.

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Words and word combinations:

– supplementary [ˌsʌp.lɪˈmen.tər.i] – дополнительный;
– package [ˈpækɪdʒ] – упаковка;
– configuration [kənˌfɪg.əˈreɪ.ʃən] – конфигурация;
– comparing [kəmˈpeər] – сравнение;
– emission [ɪˈmɪʃ.ən] – эмиссия;
– distribution [ˌdɪstrɪˈbjuːʃn] – распределение;
– simplification [sɪmplɪfɪˈkeɪʃn] – упрощение;
– prompting [ˈprɒmp.tɪŋ] – побуждение;
– regardless [rɪˈɡɑːd.ləs] − несмотря ни на что;
– recommendations [ˌrek.ə.menˈdeɪ.ʃən] – рекомендации;
– significant [sɪɡˈnɪfɪkənt] – значительный;
– proportion [prəˈpɔːʃn] – пропорция;
– addressing [əˈdres] – обращение;
– highlighting [ˈhaɪ.laɪt] – выделение
– consumption [kənˈsʌmp.ʃən] – потребление;
– variability [ˈveə.ri.ə.bl̩] – изменчивость;
– specifications [ˌspes.ɪ.fɪˈkeɪ.ʃən] – технические характеристики;
– hardware [ˈhɑːd.weər] – аппаратное обеспечение;
– envisaged [ɪnˈvɪz.ɪdʒ] – предусмотренный;
– considerable [kənˈsɪdərəbl] – значительный.

Task 2. Summarize all the ideas of the article and write an essay.
Task 3. Make a presentation based on the article.

Article 2

Task 1. Read the text below.

Effect of boiler oversizing on efficiency: a dynamic simulation study
(by George Bennett; Cliff Elwell)

Abstract

Gas boilers dominate domestic heating in the UK, and significant efficiency improvements have been associated with condensing boilers. However, the potential remains for further efficiency improvement by refining the control, system specification and installation in real dwellings. Dynamic building simulation modelling, including detailed heating system componentry, enables a deeper analysis of boiler underperformance. This paper explores the link between the space heat oversizing of boilers and on/off cycling using dynamic simulation, and their subsequent effect on boiler efficiency and internal temperatures. At plant size ratio (PSR) 8.5 daily cycles numbered over 50, similar to median levels seen in real homes. Simulations show that typical oversizing (PSR >3) significantly increases cycling behavior and brings an efficiency penalty of 6–9 %. There is a clear link between raising PSR, increased cycling and an associated decreased efficiency; however, in the UK, boilers are regularly oversized with respect to space heating, especially combination boilers to cover peak hot water demand. Current legislation and labelling (ErP and SAP) overlook PSR as a determinant of system efficiency, failing to incentivize appropriate sizing. Reducing boiler oversizing through addressing installation practices and certification has the potential to significantly improve efficiency at low cost, decreasing associated carbon emissions.

Practical application

This research provides the basis for a practical and cost-effective means of assessing the potential for underperformance of boiler heating systems at the point of installation or refurbishment. By assessing the oversizing of the boiler with respect to space heating, unnecessary cycling and the associated efficiency penalty can be avoided. Plant size ratio, as an indicator of cycling potential, can be implemented in energy performance certificates (EPCs), through the standard assessment procedure (SAP), using existing data. The potential for real carbon savings in the existing boiler stock is considerable, and the findings have wider implications for next generation heating systems.

Keywords

Building energy simulation, buildings energy performance, domestic buildings, space heating, boiler

Introduction

The UK residential heating landscape is dominated by one technology: the gas boiler. In 2007, boilers accounted for 86 % of the heating systems of England totaling over 20 million appliances, and boilers are being installed (new and replacement) at a rate of 1.2 million per year. Small improvements in the efficiency of gas boiler heating can have a major impact on national emissions; yet, a persistent performance gap between predicted and actual boiler energy demand remains, of the order of a 10 % efficiency drop. Closing this performance gap has the potential to significantly and rapidly decrease carbon emissions and energy use. Boiler systems in occupied dwellings have been shown to exhibit cycling behavior that is associated with reduced overall efficiency. The tendency for combi boilers to be oversized with respect to central heating was noted from the large typical boiler thermal output sizes compared to the heat demand of the stock. This oversizing is the probable cause of observed cycling: high numbers of short heating cycles were observed. Although those observations are consistent with the circumstances that would lead to efficiency losses, the link between system efficiency and cycling behavior has been observed but not fully explored in previous studies. This paper aims to address this research gap by simulating boiler system performance as the plant size ratio varies, and therefore relative oversizing of the heating system varies, in addition to exploring ways to avoid or mitigate the negative consequences of oversizing.

Literature review

The advent of boilers with variable rate/modulating power output levels enabled the combination of direct hot water and space heating in the same appliance. On demand, hot water requires rapid control of the heat input in order to deliver consistent hot water temperature despite a variable flow rate and cold feed temperature. Combining the two functions saves space and reduces installation complexity, by eliminating the need for storage. Peak hot water demand is proportional to the maximum flowrate expected, which is often considered proportional to the number of occupants or bathrooms, whereas the space heating demand is derived from the heat loss of the building. In practice, peak hot water demand is mostly significantly greater than the space heating demand, so the design, sizing and selection of combi appliances are based on domestic hot water (DHW) capacity. For example, a boiler installed in a dwelling with two bathrooms would be required to deliver up to 13 L/min of DHW (at a temperature increase of 40 K), necessitating 30–36 kW of DHW capacity. Studies of real energy demand and survey data estimate the mean actual space heat load of a UK dwelling to be around 6–8 kW, with an internal-external temperature difference of 23 °C, corresponding to a cold winter day. A combination boiler should be capable of meeting these significantly mismatched space and water heating outputs.

The (mis)matching of boiler output to heat demand is commonly quantified by means of the plant size ratio (PSR), a succinct term to refer to the ratio of maximum heater thermal power output ($\dot{Q}_{\mathrm{H}}$) to the building design steady state heat loss ($\dot{Q}_{\mathrm{B}}$)

$$PSR = \frac{\dot{Q}_{\mathrm{H}}}{\dot{Q}_{\mathrm{B}}}$$

Space heating design load ($\dot{Q}_B$) is calculated based on the steady state building heat loss for a chosen temperature difference across the building fabric (with heat transfer coefficient, U (W/m^2K) and total surface area, A (m^2) accounting for ventilation losses (with coefficient, C_u ($\frac{W}{K}$). A design day with 21 °C internal and –2 °C external temperature is typical, although a regional calculation method is recommended in BS EN ISO 15927-5 based on historical coldest months, which could lead to design external temperatures between approx. 0 and –6 °C (ashrae-meteo.info). The below equation shows the building space heat loss for plant size calculation

$$\dot{Q} = \sum(UA\Delta T) + C_u \, \Delta T$$

If the system is expected to provide constant heating, a boiler thermal output may be selected directly on the basis of the design day heat demand. However, heating schedules are often operated intermittently due to occupancy, comfort requirements or tradition. Accordingly, a heating system multiplication factor is used to account for the cooling that will occur outside of the heat schedule and the extra thermal power required to return the heated space to the required temperature within a reasonable time. CIBSE offers a simple set of discrete multiplication factors to identify the required design heat load, separating buildings into fast or slow thermal response, based on construction type, inferred thermal mass and thermal time constant. The factors replicated in Table 1 show that for buildings with 12 or more hours of continuous heating, no adjustment to the plant size is deemed necessary regardless of building thermal response. When the heating schedule is shorter, notable increases in plant size are recommended for fast thermally responding houses, up to a practical maximum of 2.8.

Table 1 – Plant size multiplication factors according to building thermal response a ratio of cyclic response to thermal transmittance

Daily hours of heating ON time t_0	Multiplication factor acc. Building thermal response	
	slow	Fast
12	1.0	1.0
6	1.1	2.0
4	1.2	2.8

In practice, the required heater power requirement (with a fixed multiplication factor relating to the building fabric) varies with time as the building heat loss changes with outdoor temperature (in contrast to the PSR which is fixed and dependent on specified boiler thermal output and theoretical peak building steady state heat loss). Since the design day heat load is chosen to account for the coldest expected days, the actual heat load for the majority of days in any winter is expected to be significantly lower, as shown by Fig. 1. This issue is exacerbated in milder winters, with a correspondingly lower building heat load and larger mismatch, and in the shoulder seasons of each year.

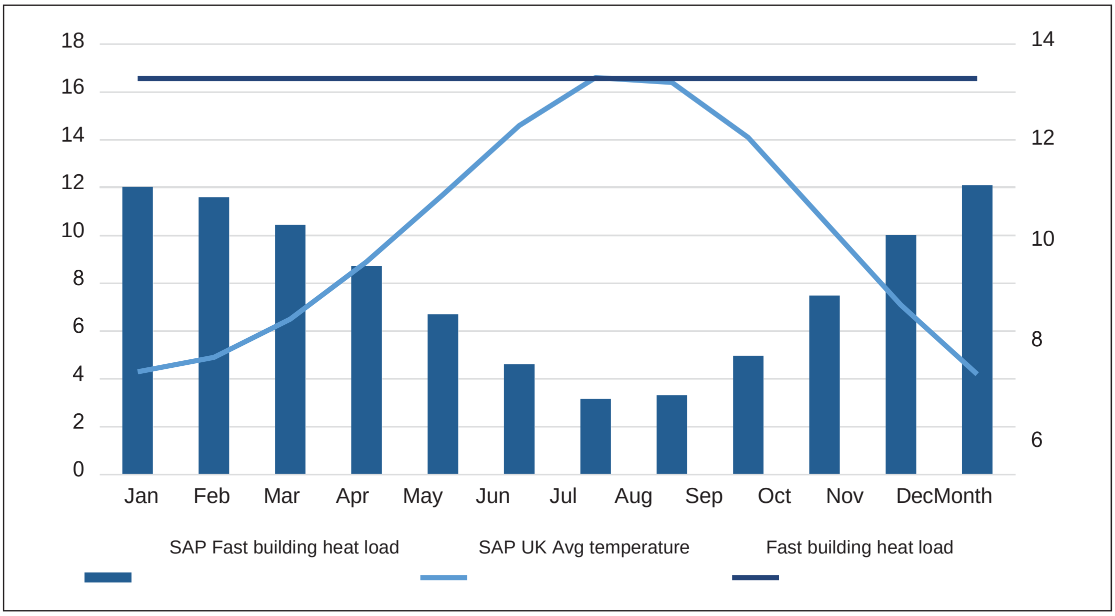

Figure 1. Design day and temperature dependent building heat load with CIBSE factors for intermittent operation, 'fast' low thermal lag building shown

Modulation of the boiler heat output aims to match this heat demand and supply. Current pneumatically controlled premix gas valve technology is limited to a modulation ratio of approximately 1:10 in newer boilers, with 1:6 being more common. A practical result of this limited modulation range is that a boiler with maximum thermal output of 36 kW can normally modulate to a minimum of 6 kW. This suggests that it is likely that combi boiler heating systems have to cycle on and off to match the space heat demand, with implications for the in-situ efficiency.

Although the efficiency of gas boilers is relatively robust regarding part load operation, it is not independent thereof, with testing for product energy labelling reflecting that fact, with measurements at full and 30 % load. Boiler efficiency, as a percentage of useful heat produced relative to energy consumed, is subject to the operating conditions of the boiler at that time. Important factors include the gas/air ratio, flue gas temperature (itself a function of heating water temperature and heat exchanger effectiveness) and heat power modulation level. Furthermore, on/off cycling is known to be a major influencer of efficiency, but is less well understood in practice. Trials, such as the BRE condensing boiler assessment,[4] have explored the real efficiency of boilers in operation and have led to assumptions around efficiency adjustments that find their way into the calculation methods, such as those for the standard assessment procedure (SAP) used in energy performance certificate (EPC) generation. The influence of the thermal output range of a boiler on efficiency in practice is covered from a theoretical perspective in handbooks and guidelines for professionals in the field, e. g. the Buderus Handbuch für Heiztechnik. These texts describe that standby losses may be greater for a larger boiler due to increased surface area of the boiler itself; however, this maintains focus on steady state conditions and not on real dynamic operation. Performance factors such as start-up/shutdown sequences, standby and running losses are inherently dynamic. Start/stop losses, associated with the switching on and off of boiler operation during a scheduled heating period, become more significant with short cycles. Orr et al. reported an exponential relationship[3] rising from 1.5% for 3 min boiler runtime to 11.8 % for 10 s runtimes. The same study reported widespread underperformance of boiler systems, oversizing of combination boilers and a correlation between low monthly load factor and decreased efficiency.

Confirmation of the prevalence of oversizing and short operation cycles has come from analysis of high frequency boiler diagnostic data, in this large dataset of 209 dwellings 20 % of boilers averaged less than 2.5 min per firing. A limited case study found that 25 % of all firings for combi boilers were less than 2 min. Current efficiency testing of boilers for space heating is conducted at steady state and the representative efficiency, which is placed on the energy label, can be arithmetically derived from two steady state load conditions with a weighted average. Tests are conducted at maximum and 30 % power modulation levels using controlled flow and return temperatures; the results are combined in a weighted average (30:70 maximum to lower modulation measurement). In contrast, the efficiency measurement for the DHW is based on a hot water demand (tapping) schedule (EN15502), which simulates typical daily hot water demand schedules incorporating various tapings of different flowrates and temperatures in the time domain and ensuring the dynamic response of the boiler is captured.

To simplify the functional efficiency of a boiler and its system into a representative value is a challenge, made more complex when such a value may be utilized for multiple aims, e. g. product labelling, consumer comparison and standardized building energy assessment (SAP). SAP uses the singular figure of the Seasonal Efficiency of Boilers in the UK (SEDBUK) rating (if available in the Product Characteristic Data Base (PCDB) as the starting point of its procedure to calculate gas demand from the building heat load. Adjustments are made to decrease the assumed efficiency of all boilers due to previously observed underperformance. Positive adjustments are made according to other factors deemed beneficial to system performance, such as low temperature emitters and modern controls. However, the methodology inherits the assumption in the original SEDBUK efficiency that the boiler efficiency can be derived from steady state measurements. Inclusion of real-world dynamic behavior in the efficiency estimation of boilers can support improved energy labelling, installation quality and reduced energy bills for consumers. Recent simulations of the dynamic performance of heating systems have shown that standardized, steady state, methods to estimate energy use do not accurately capture the heat demand, supply and internal temperatures. However, the relationship between the dynamic behavior of boiler-based heating systems and their efficiency has not been widely studied. Dynamic simulation and field studies of heating system performance can be used to investigate these relationships in detail, including their impact on efficiency. Furthermore, potential mitigating strategies, for existing and future boiler systems, can be explored, which may also pave the way for the next generation and emerging heating systems in the UK, such as heat pumps, and the transition to low carbon heating. This paper seeks to bridge the gap between observed boiler underperformance, dynamic behavior and boiler operating/installation parameters. From within a simulation environment, the suspected important performance driver of PSR was varied systematically to induce the cycling behavior previously seen in the field and the impact on boiler efficiency quantified. The magnitude of underperformance attributable to oversizing was assessed, possible mitigation strategies discussed and methods for integrating the new knowledge into installer practice and policy tools explored.

Methods

This paper systematically addresses, in a simulation environment, the efficiency impact of boiler sizing, using the example of a common UK house type and explores some means of mitigating the challenges of over and under sizing boilers. Simulated heating operation addresses the widely reported intermittent heating schedule in UK residential dwellings and the evidence of general oversizing of boilers, which is associated with high levels of cycling. A boiler cycle is defined as an operational period which contains both one central heating ON (>0 % modulation) period and one-OFF period (0 % modulation), where the boiler operation is not interrupted by user intervention in the form of hot water demand or similar. Since the simulation covered only space heating operation, all cycles are categorized as central heating (CH) cycles and are therefore determined by the interaction between the characteristics of the space heating system and the building heat demand. The simulations performed aim to strengthen the depth of understanding around dynamic behavior of domestic heating systems and point the way to improving real-world performance. Below, firstly, the simulation environment is discussed, followed by the simulation parameters for both the house and the heating system.

BTSL Simulation environment: TRNSYS and Simulink

The BTSL (Building Technology Simulation Library) model is a fully dynamic engineering model with a library of simulation blocks such as archetypes of buildings, heating system components and users, which can be linked within the MATLAB Simulink environment; the interaction of these elements is shown in Fig. 2. BTSL operates as a co-simulation between TRNSYS building model and MATLAB-based heating and user simulation. BTSL allows for modular creation of a building model, whereby the heating system and building characteristics, user behavior and weather can be chosen. The aim of such co-simulations is to allow developers to extend the scope of simulations by adding simulation blocks of different types and depth to the central building model. This type of hybrid simulation environment is also possible with the popular Energy Plus building simulation software using the Building Control Virtual Test Bed (BCVTB).

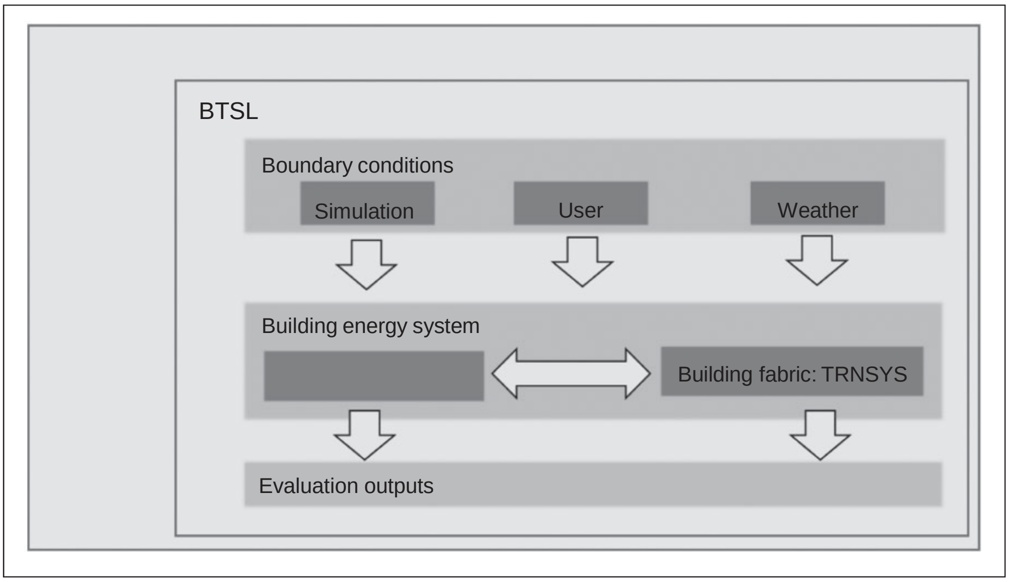

Figure 2. Schematic representation of hierarchy in BTSL simulation environment

BTSL is a proprietary heating system emulation tool for product development at Bosch Thermotechnology, developed from their previously validated *LabHouse* tool. It has been developed and expanded to include a wide range of heating ventilation air conditioning (HVAC) components such as radiators, thermostatic valves, heat exchangers, cooling coils, fans and pumps: the depth of detail at which a user can specify the heating system is a key advantage to BTSL over publicly available tools. In addition, the transient behavior of the heating appliance is modelled through time response parametrization, control feedback loops and the associated control algorithms. This type of proprietary modular concept is used in industry to simulate heating systems under a number of installation environments and verify performance and control strategies. An analogous modular construction of simulation in the MATLAB environment with a TRNSYS Building model has been suggested, which served the purpose of evaluating the possible intervention options, building and HVAC system, available in a building upgrade situation.

BTSL is designed to support the development of heating systems and their controls and thus has a high level of flexibility with regard to the heating system library block in Simulink, and uses an existing building model, TRNSYS, to simulate the building fabric. The TRNSYS building model, known as “Type 56”, is a modular transient system simulation program which meets the general technical requirements of the European Directive on the Energy Performance of Buildings, making TRNSYS a potential candidate for compliance with the directive’s implementations in various EU countries. BTSL is utilized in this paper to explore how a fully dynamic national calculation method, such as the UK’s Standard Assessment Procedure, would reveal interactions between boiler, PSR and controls. The model used here builds on previous research into the dynamic performance of heating systems; utilizing the same building model and many of the same heating system components the BTSL model was able to reproduce SAP results, with some adaptation of simulation blocks. The modelling strategy built on using dynamic inputs (weather, solar gain, setpoint temperatures) in dynamic representations of the physical elements of the building/heating system. Most aspects were implemented using standard components of the library, such as the dynamic weather, building and heating system models. Using this approach, the model can draw directly on the same control algorithms implemented in Bosch heating appliances and the thermal response characteristics of Bosch boilers.

House and heating system parameters

The chosen test case is a detached east-facing two-story house with an above average standard of efficiency (C80 rated EPC) and equipped with a typical gas combi-boiler heating system. The house model is the same as used in previous research within the BTSL simulation environment. A summary of the building properties is listed in Table 2.

The building, as modelling in TRNSYS within BTSL, was a simple four room layout (two per floor) with the front room on the ground floor designated as the main living space (30 % of total floor area as in Table 2). The construction comprises cavity-filled walls (U = 0.19W/m^{2}K), dual-pitched warm roof (U = 0.13W/m^{2}K), solid floor (U = 0.18W/m^{2}K) and double-glazed windows (U = 0.12W/m^{2}K), the overall building thermal characteristics are in Table 2.

Table 2 – Selected building and heating system simulation parameters

Parameter	Value	Unit
SAP parameters HLP (heat Loss Parameter)	 1.3652	 W/m^{2}K
TMP (thermal mass parameter)	283	kJ/m^{2}K
TFA (total floor area)	100	m2
Living area (Zone 1)	30	m2
Window area	23	m2
Window orientation	East	–
Main heat source	Gas Combi Boiler (Condensing nominal 90 % efficiency, size varied in simulations) Modulation range 1:5	
Setpoint room temperature	21	C
Heating schedule weekdays	07:00–09:00 16:00–23:00	
Heating schedule weekends	07:00–23:00	
Heating system emitter type	Radiators (sized according to 80/60 flow/return temperatures)	–
Heating system control	Programmer, Room Thermostat and Thermostatic Radiator Valves (TRVs)	–

The combi boiler was taken from the BTSL library, which uses a physically representative model of the thermal characteristics, derived from the lab testing of a major boiler manufacturer. The boiler model also includes all necessary ancillary components, such as fans, pumps and control systems. Importantly for the analysis, this includes real-world boiler control algorithms such as start-up sequences, ramp rates, an anti-cycling control. This detailed model allows for realistic accounting for the electrical energy consumed during boiler operation, which is then used in the efficiency calculation together with the gas consumption. The control algorithms are also representative of commercially available appliances in the UK.

Applying the UK standard SAP analysis to the simulated dwelling, the design day heat load is 3.3 kW, used for PSR calculations in Table 3, which contains the range of PSRs and control parameters simulated in the BTSL environment with the house described in Table 2. The range of PSR was informed by the general observations of installed combi boilers in the UK; it ranges from highly oversized (PSR 8.5) down to theoretically undersized boilers of PSR 0.5.

A PSR of 8.5 corresponds to a 28 kW boiler, a typical maximum thermal output of combi boilers (corresponding to ∼10 L/min DHW capacity). Smaller sizes (corresponding to PSR less than 8.5 in this simulated case) are not commonly included in the product offerings of major manufacturers, because they are not able to provide ‘on demand’ DHW at a high enough flow rate to meet expected customer requirement. The range of PSR used in this simulation does not include higher PSR than typically installed for a property of the type modelled, but does include significantly lower PSR than generally available, to explore its impact on operational efficiency (dictating the minimum operational power level of the boiler).

Reducing the size of a boiler will increase the time taken for a dwelling to reach thermostat set-point; therefore, ‘heat up optimization’ was included in the simulation options to investigate a possible means of compensating for boiler size. ‘Heat up optimization’, available in some modern controls, interprets the heating schedule not as the strict definition of heating system activity but as a literal interpretation of the desired internal temperature and adjusts the operation of the heating system appropriately. Heat up times are moved outside of the heating schedule, with the aim of delivering the desired room temperature at the required time. This will inevitably increase the duration of heating system operation, impacting gas consumption, but may reduce the need for oversizing, with consequent reductions in boiler cycling and potential improvements in efficiency.

Table 3 – Summary of parameter space covered by simulations

Parameter	Options/Range	Notes
Plant size ratio Heat up optimization	8.5 3.0 2.0 1.0 0.5 ON or OFF	Defined as: Ratio Of boiler rated output/ building design day heat loss at an external temperature Of −2 ^{0}C, excluding free heat gains. Control algorithm which activates the heating system before the scheduled time in order to achieve the desired internal temperature at that time, avoiding delayed heat up.

Results

Simulations were carried out on the 10 parameter combinations listed in Table 3, for one full calendar year capturing the internal temperatures, heat demand, gas consumption and the dynamic response of the heating system as displayed in a representative January day in . Although the simulation was conducted for a full year, this figure illustrates in a single day the impact of a high, 8.5 PSR, thermal output boiler, with finite modulation range. The boiler does not operate at full power after the first seconds of start-up and, after an initial heating up period, the boiler enters extended periods of cycling characterized by repetitive periods of boiler operation separated by boiler inactivity, on a timescale of minutes, seen more clearly in . In contrast, the PSR 1 system operates at full power continuously throughout the morning and evening heating periods; the intermittent heating schedule is not suited to this low PSR: it is undersized according to industry norms (CIBSE).

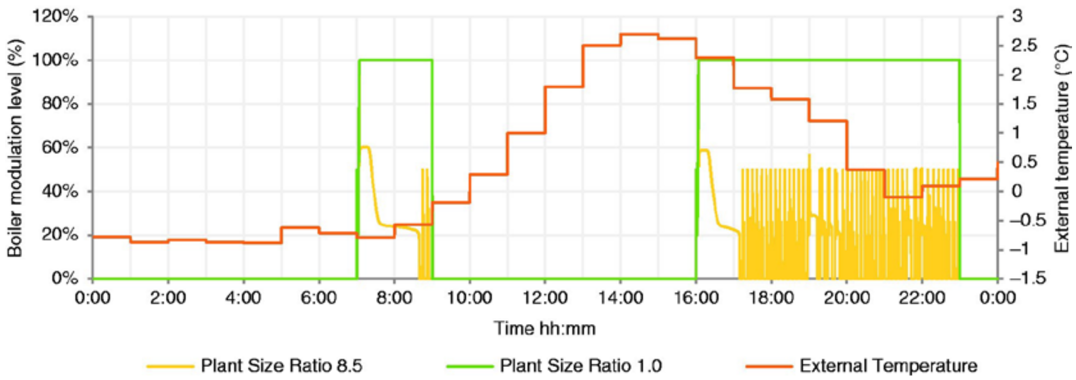

Figure 3. January day, PSR 8.5 and PSR 1 boiler modulation levels

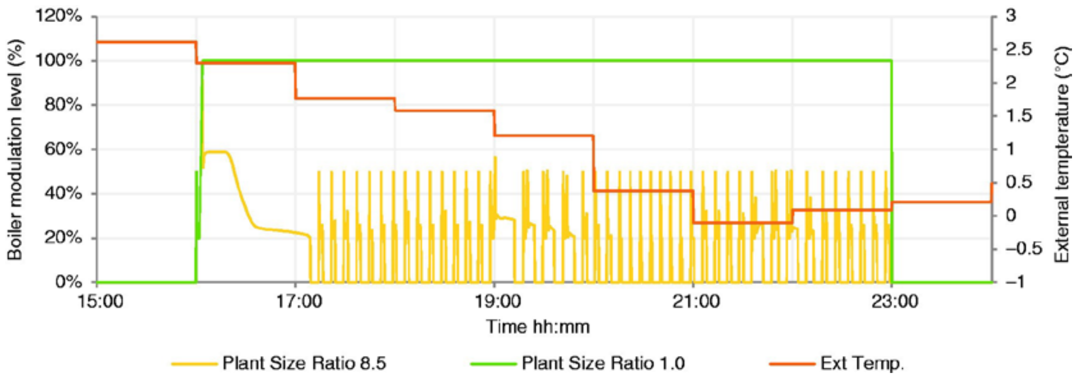

Figure 4. Detail of boiler modulation on January day, PSR 8.5 and PSR 1

Cycling and efficiency

By aggregating over the simulated year, the predicted cycling behavior across the PSR range can be compared, as shown in. It shows an increase in cycling behavior as the PSR increases. also shows that the 'heat up optimization' algorithm increases the number of observed cycles of boiler operation at a given PSR, which is explored below.

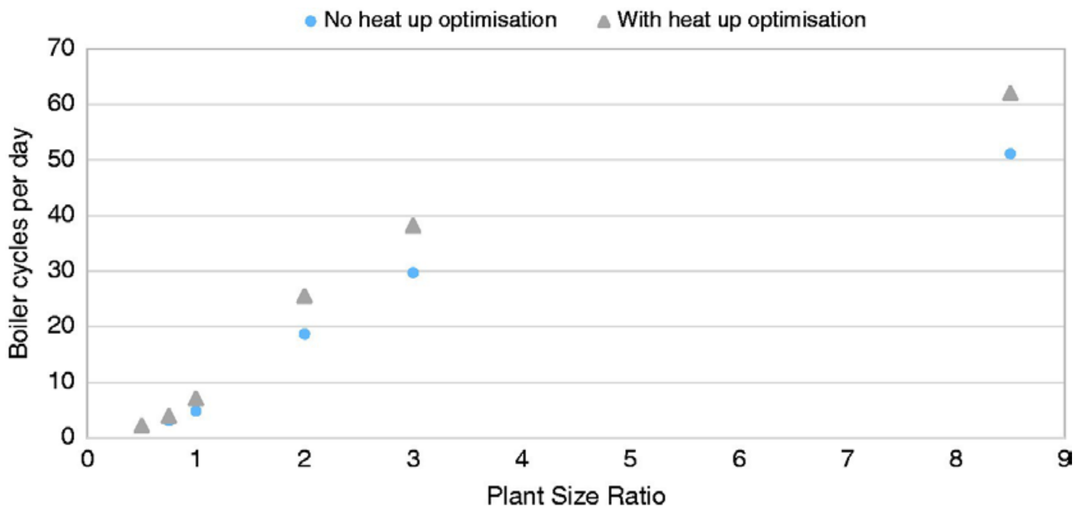

Figure 5. Cycles per day across PSR, with and without 'heat up optimisation'

A heating system, which is continually and ideally matched to the changing thermal demand of the dwelling throughout the heating season, following the instantaneous heat demand, would be expected to average at most two cycles per day, coinciding with the start and end of each heating period, with no cessation of heating within the period. Such an appliance would need to be infinitely modulating within the range of building heat demand and able to react instantaneously. shows that only the smallest PSR of 0.5 results in continuous heating operation during the daily heating periods. Over 50 cycles per day were observed in the PSR 8.5 simulation, a good match to the median value of 53 from field data, Cycling is a clear symptom of oversizing of the heating system with respect to the building heat demand. The defining features of the modern heating systems that contribute to this undesired behavior are sizing and control. The boiler is unable to modulate sufficiently low to match the required demand for heat due to both the oversizing of the boiler with respect to the building heat demand combined with its finite modulation range, where the minimum output is set as a fixed percentage of maximum output. In the case of combi boilers, this is dependent on peak hot water demand, not space heating. Control of the boiler modulation also plays a role and simple on/off thermostatic control can limit the ability of a boiler to match the space heating requirement in cases where the modulation range allows it. The duration of the heating operation period also plays a role, as discussed above, with a higher PSR required to meet the additional power requirements of warming up the building after enforced intermittent operation from the heating schedule. The impact of PSR on efficiency (accounting for gas and electrical consumption of the appliance) was investigated, see Fig. 6, showing that in these simulations the system efficiency decreased as PSR increased, corresponding to an increase in cycling behavior.

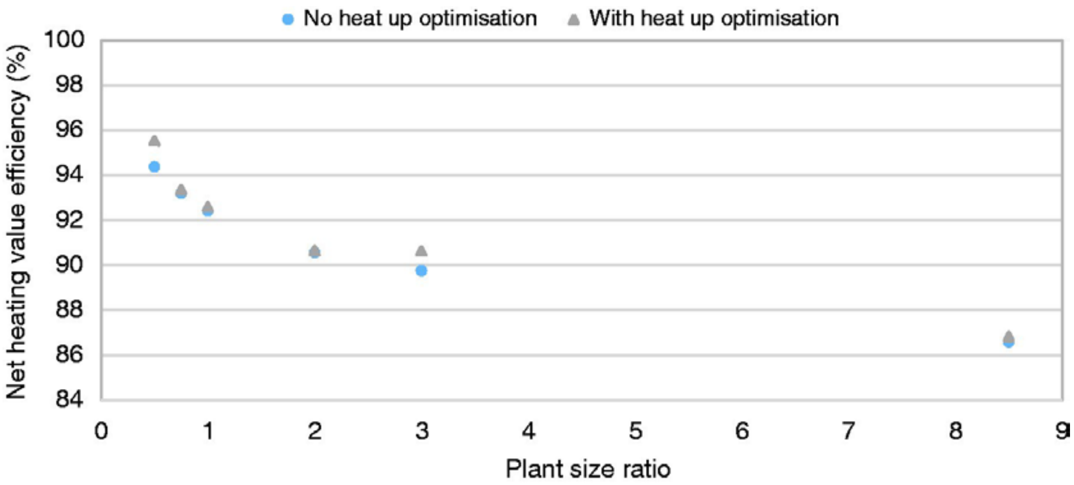

Figure 6. Net heating value boiler efficiency across PSR, with and without heat up optimization

Optimum efficiency of boilers is reached during sustained steady state conditions with low water temperature in the heating circuit. For intermittent heating and variable external temperatures, the interplay of operational parameters becomes more complex and it is generally held that longer operating times can be conducive to improved efficiency due to the lower impact of standby losses and the potential[7] for lower average flow temperatures coming from the boiler and returning from the radiators. However, despite the longer running times, Fig. 6 shows that the net efficiency effect of the ‘heat up optimisation’ function is marginal, with less than 0.5 % difference in efficiency for PSR 0.5 and no difference at the largest PSR of 8.5.

Internal temperature and energy demand

In intermittent operation, it is striking that an oversized boiler system, with PSR of 8.5, is unable to reach the required internal temperature for most of the 2 h long morning heating period during cold weather, as shown in Fig. 7. All smaller boilers in the simulations also failed to meet the setpoint temperature in the morning heating period. The PSR 1 boiler, for example, would have been unable to deliver reasonable comfort throughout the colder winter days, also shown in Fig. 7.

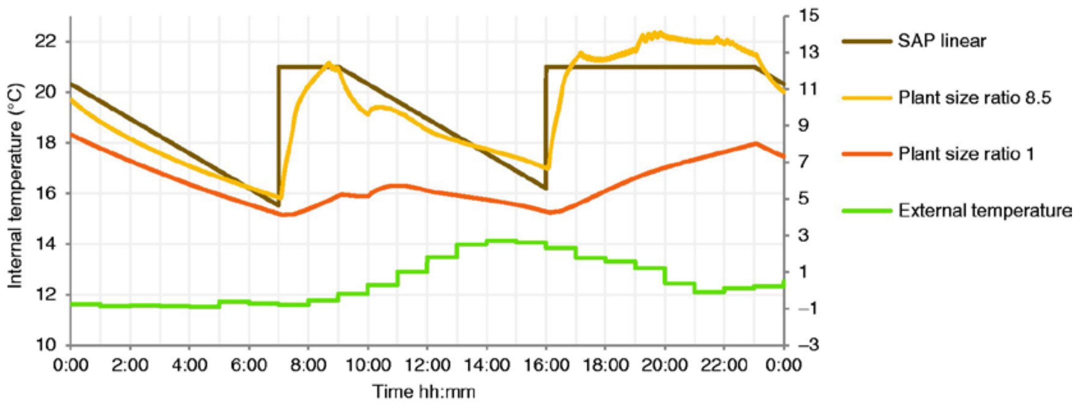

Figure 7. Internal living area and external air temperature for SAP and PSR 8.5, PSR 1 without 'Heat up optimization'

The alternative control strategy, to simple intermittent boiler timing, considered here is the 'heat up optimization' function, which aims to heat the property to achieve setpoint during the specified hours. This can lead to the boiler operating hours earlier than if it only operates at the start of the heating schedule. Heat up optimization requires an estimate of the thermal properties of the building, and by extending the heating period, it counterbalances the effect of intermittent heating, reducing the need for boiler oversizing, as shown in Fig 8. The longer running hours of systems with heat up optimization are successful in delivering more consistent internal temperatures, close to setpoint in operating hours, than those using a standard intermittent schedule (Fig. 7).

The relationship between energy demand and the mean internal temperature (MIT) of the property, for different PSR, with and without heat up optimization is shown in Fig. 9. Simulations with a fixed heating schedule and no heat up optimization, shown in red, show a steady increase in gas demand with MIT for PSR 0.5 to 2. This is associated with an increase in boiler output achieving higher temperatures during the schedule; with a corresponding increase in energy demand, the reduction in efficiency (Fig. 6) has only a small effect. However, for PSRs greater than 2, the drop-in efficiency is clear: there is no significant change in internal temperature despite an increase in gas demand.

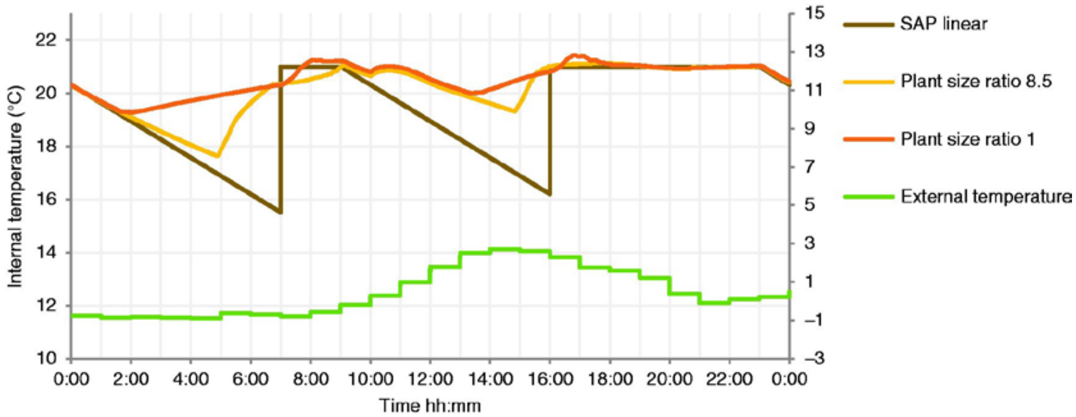

Figure 8. Z1 Internal temperatures across PSR with 'heat up optimization

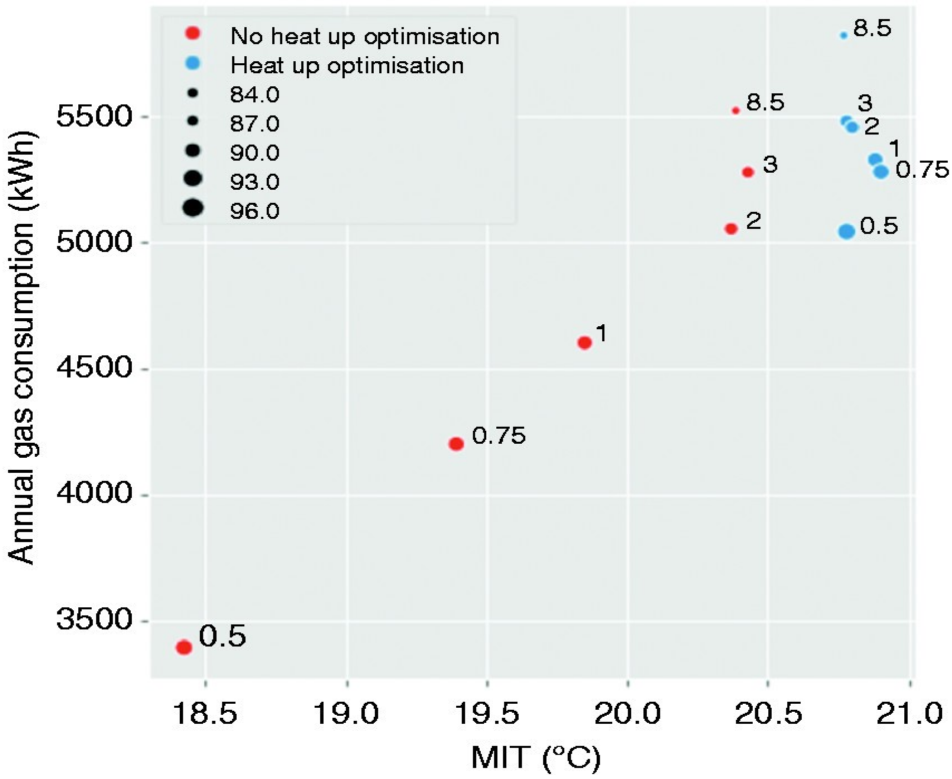

Figure 9. Annual gas consumption plotted against building mean internal temperature (MIT), size of data points indicates efficiency, blue circles for heat up optimization active, data labels show PSR

Whilst low PSRs of 1, 0.75 and 0.5 delivered the highest efficiencies (Fig. 6), when constrained by a fixed heating schedule, with the resultant intermittent heating, they were unable to provide enough heat to raise the room temperature to the desired setpoint. This led to a corresponding drop in MIT and heat energy delivered. However, the 'heat up optimization' function has overcome this issue, leading to a longer effective heating period and delivering higher MIT than the simulations without this feature (Fig. 9). Importantly, the results for heat up optimization control show that the same MIT is provided at an increasing efficiency as the PSR decreases, offsetting the increased operational periods. Thus, the dwelling can achieve higher mean internal temperature with less energy demand by operating longer.

Discussion

The oversizing of boilers is endemic in the UK stock, and therefore the associated efficiency reduction caused by on/off cycling is likely to be systemic, causing widespread underperformance of boiler heating systems. The simulations with lower boiler thermal output ranges and PSR better matched heat demand and supply across a year. However, whilst this improved efficiency, it did so at the expense of thermal comfort: the dwelling did not achieve setpoint temperature during the morning heating period for this intermittent schedule. Indeed, even with a PSR of 8.5, the internal temperature did not achieve setpoint for significant parts of the schedule. A key cause of this inability of the heating system to meet the demanded temperatures is the ability to distribute heat throughout the property: it is limited by the pump flow rate, pipework and the size of emitters. Increasing emitter size is likely to improve the system’s ability to deliver the demanded temperature, although the potential impact on cycling, and efficiency, is not clear but should be considered in the context of hydraulic parameters such as pump control, hydraulic balancing and thermostatic radiator valves.

The property simulated in this study has above average thermal performance, in EPC band C, score 80, with a heat loss of 136 W/K compared to an average in the UK of approx. 300 W/K. The link of PSR to efficiency enables the detrimental efficiency effect of cycling across houses with different heat loss (either through construction or retrofit) and across seasons to be estimated since both can be interpreted as a change in effective PSR. A property with the same number of occupants and bathrooms, but worse levels of insulation, would have the same water heating demand, used to set the boiler size, but higher space heat demand. Such lower insulated properties would, in effect, have a smaller PSR and therefore experience less boiler cycling, and lower associated efficiency reduction; however, they would still experience significant penalty. The findings of this research have implications for policymaking, and the way policies are manifested through regulations. Real boilers are classified according to their measured efficiency and are required to have an energy label (EuP legislation) displaying the rated efficiency. Measurements are made under steady state conditions in the laboratory with fixed flow and return temperatures at maximum and 30 % modulation level according to the current standard. A weighted combination of these efficiency values is made to display on the energy label or use in national calculation models such as SAP for the creation of EPC. Although such measurements are not meant to be accurate predictions of real-world performance, they should be indicative of the relative benefits of products in the case of EuP labelling, and of system performance, in the case of EPCs. The results here show that the same boiler type can operate at significantly different efficiencies according to its relative size compared to the building heat load. Adjusting the boiler efficiency according to its relation to the expected heat demand, for example from a SAP estimate, would improve the accuracy of boiler energy labels and the resulting building energy calculations. Incorporating the PSR and modulation range into the SAP methodology, and the resulting EPCs, could be simply undertaken without extra or time-consuming assessment criteria. The make and model of boiler is already collected as part of the assessment of the heating system, supplementing this with the boiler size (both minimum and maximum thermal output) from the boiler data plate or documentation would facilitate estimation of its ability to match the building heat demand. The efficiency losses associated with a consequent boiler cycling may then be estimated, either using a standard adjustment curve, or ideally by using the testing results for the specific boiler. Similarly, SEDBUK ErP labelling may be modified to support improved performance across wider power ranges, lower than the 30 % minimum modulation currently used, to better match heat demand. Such measures may incentivize the installation of lower power boilers, combined with appropriate controls, such as heat up optimization, as well as incentivize manufacturers to produce heating systems capable of operating at high efficiency across a range of outputs that relate to the real heat losses of dwellings.

Even a moderate increase of boiler stock efficiency can have significant carbon abatement potential, in the UK approximately 3000 GWh of gas is saved per 1 % improvement, equating to 612 $MtCO_2$ per annum: a significant low-cost saving on the way to net zero carbon. Besides the 'quick win' carbon saving potential with the existing stock of boilers, the relevance of correct heating system sizing is even more relevant for low carbon heating technologies. The efficiency of systems such as heat pumps is known to be more sensitive to system specification than boilers; bringing in measures of system performance grounded in real-world operation, and tools to support their optimization, will support the transition to low carbon heating.

Conclusions

This paper investigates the potential for reducing the energy required to heat homes with boilers, the dominant heating technology in the UK, by addressing their sizing, control and system specification. Dynamic simulation of the heating system, and the building within which it is located, has been undertaken to investigate causes and potential solutions to system underperformance. In particular, this research focuses on the link between the space heating oversizing of boilers and on/off cycling. Simulations of the dynamic performance of boiler heating systems within a UK dwelling have shown that typical oversizing (PSR 8.5, 28 kW boiler) resulted in over 50 unnecessary CH cycles per day (corresponding closely with field observations of a median of 53[6]) and efficiency of less than 88 %. The modelled efficiency of the PSR 8.5 boiler system is 4 % lower than minimum Part L Building Regulation requirements on which carbon budget projections and SAP assessment are made, and is associated with a minimum modulation level that is significantly higher than the heat demand for the house in most external conditions. Reducing this PSR to 1, thereby also lowering the minimum modulation level by a factor of 8.5, was found to improve efficiency by 4 %, ~92 % efficiency, with further efficiency improvements associated with lower PSR. Simulations for low PSR boilers may not deliver the required internal temperatures throughout the year, but illustrate the impact of minimum modulation level on the system efficiency. This loss of efficiency, caused by a mismatch between the building heat demand and the minimum modulation level at which the boiler can operate, is associated with repeated on/off cycling, which increases electrical losses associated with necessary start-up/shutdown sequences and reduces condensing, due to the inconsistent return temperature. The link between on/off cycling and efficiency enables the former to be used as a proxy for good system operation, and, as a simple parameter to measure, may be employed to diagnose performance issues in the stock.

Whilst efficiency is an important metric of heating system performance, CO_2 emissions and energy bills are dependent on total gas consumption: system efficiency must be combined with the duration and power of operation. Additionally, the function of the heating system should be to adequately fulfil the occupant(s) comfort requirement and deliver the expected internal temperatures, regardless of the theoretical efficiency of the system. The heating system should be designed and operated to maintain the minimum required internal temperature for the lowest end energy demand.

The simulated results show that, in the case of the building modelled, a boiler sized closer to a PSR of 1 with heat up optimization would be able to maintain a mean internal temperature at the level requested, better achieving the morning heating setpoint (Fig. 7 and 8), for a lower energy consumption than an oversized boiler with PSR 8.5 and without heat up optimization. This suggests that installing a boiler with

PSR significantly smaller than typical, or with a lower minimum modulation level, but using heat up optimization, would be preferable in terms of emissions and achieving thermal comfort. Simulation of the impact of decreasing the lowest heat output of boilers on total national carbon emissions is the subject of further research, which could be achieved through widening modulation ranges of appliances or curbing the trend for oversizing based on peak DHW demand. All options to address this issue depend on the thermal properties of the stock, the characteristics of existing boilers, and assumptions of the heating use. The decrease in energy use associated with lower PSR boilers and heat up optimization leads to both raised internal temperatures outside the heating schedule and to a decreased capability to deliver on demand hot water. Whilst increased temperatures outside heating schedules may deliver some advantages to occupants, studies of hybrid heat pumps and heat pumps have highlighted potential sleep disruption from warmer night time temperatures; mitigation strategies may be required. The rate of hot water delivery from low PSR combi boilers may also be insufficient to meet consumer demands, falling below the sizing guidelines currently employed, requiring the use of water storage, with associated space requirements, to deliver the required flow rate.

Fundamental hardware issues of plant size have lasting implications for the efficiency of the system and simple measures, such as software and changed schedules, will not be sufficient to compensate for a problematic underlying system specification. For example, extending the anti-cycle time (the parameter which defines minimum time between starts) may alleviate the problem slightly but risks inadequate heating control and customer dissatisfaction.

Regulation informs and restricts the development of the technology it governs (such as the step change to condensing boilers in the UK in 2005), a failure to address the real performance of a technology in regulations, as for boiler efficiency labelling, may lead to its optimization for the laboratory, rather than the home. Disparities between real-world performance and reported efficiencies of heating appliances have been widely reported, and boilers are no exception. Crucially for consideration here, the reported underperformance of up to 10 % has not been linked to a particular root cause and has been taken as a systematic underperformance when integrated into policy instruments such as SAP and EPCs. The results of the simulations presented in this paper highlight the minimum modulation power, set by the plant size ratio, as a major contributing factor to the boiler performance gap, with implications for the policies and practices governing heating systems.

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Words and word combinations:

- boilers [ˈbɔɪ.lər] – котлы;
- appliances [əˈplaɪ.əns] – техника;
- assumptions [əˈsʌmp.ʃən] – предположения;
- consumption [kənˈsʌmp.ʃən] – потребление;
- condensing [kənˈdens] – конденсация;
- fundamental [ˌfʌndəˈmentl] – фундаментальный;
- underperformance [ˌʌndəpəˈfɔːm] – неэффективность;
- associated [əˈsəʊʃieɪtɪd] – связанный;
- emerging [ɪˈmɜː.dʒɪŋ] – возникающий;
- disruption [dɪsˈrʌpt] – разрушение;
- measured [ˈmeʒ.əd] – измеренный;
- modelled [ˈmɒd.əl] – смоделированный;
- increases [ɪnˈkriːs] – увеличивается;
- modulation [ˈmɒd.jʊ.leɪt] – модуляция;
- measurements [ˈmeʒ.ə.mənt] – измерения;
- requirements [rɪˈkwaɪə.mənt] – требования;
- approximately [əˈprɒksɪmətli] – примерно;
- achieving [əˈtʃiːv] – достижение;
- significant [sɪɡˈnɪfɪkənt] – значительное;
- grounded [ˈɡraʊn.dɪd] – заземленный.

Task 2. Summarize all the ideas of the article and write an essay.

Task 3. Make a presentation based on the article.

Article 3

Task 1. Read the text below.

Study of novel solar assisted heating system
(by Gareth Davies, John Blower, Richard Hall, Graeme Maidment)

Abstract

The potential for energy, carbon dioxide equivalent (CO_2e) and cost savings when using low emissivity (low-ε) transpired solar collectors (TSCs), combined with heat pumps in a range of configurations, has been investigated using computer modelling. Low-ε TSCs consist of metal solar collector plates with a spectrally sensitive surface, perforated with holes. Ambient air is drawn through the holes and heated by convection from the solar collector plate, increasing the air temperature by up to 25 K. The heated air can be used for e.g. space heating, or pre-heating water in buildings. The models developed have been used to compare the performance of low-ε TSC/heat pump heating systems in small and large buildings, at a range of locations. The model results showed savings in energy, CO_2e and costs of up to 16.4 % when using low-ε TSCs combined with an exhaust air heat pump compared with using the exhaust air heat pump alone.

Practical application

If the UK is to meet its target of reaching net zero greenhouse gas emissions by 2050, it will be necessary to adopt low or zero carbon heating technologies. The novel low emissivity transpired solar collector device investigated can contribute to this. Its advantages include: (i) utilizing solar radiation; (ii) readily integrated with existing heating systems e.g. heat pumps; (iii) significant energy, CO2e emissions and cost savings; (iv) low cost device; (v) minimal energy input i.e. one small fan; (vi) can be retrofitted to existing buildings; (vii) its benefits were applicable at all of the (wide range of) locations tested.

Keywords

Transpired solar collector, heat pump, low carbon, building heating, energy, carbon and cost

Introduction

The UK Government has recently set a new climate change target of reaching net zero greenhouse gas (GHG) emissions by 2050. Since 1990, the UK has reduced its carbon emissions by 43 %, mainly as a result of carbon reduction measures in the power sector, however, significantly more radical solutions and technologies will be needed to meet the new target of zero emissions by 2050. One area of focus will need to be heating, as this accounts for approximately one third of the UK's carbon emissions and about half of its energy consumption. In 2018, the European Environment Agency reported that the UK has one of the lowest shares in Europe for the use of renewable energy for heating and cooling i. e. 7 %. There is therefore an urgent need for alternative, flexible, low or zero carbon, renewable energy systems for use in buildings. Transpired solar collectors (TSCs) are one such technology, which can be used to facilitate the capture of solar thermal energy for heating in buildings. TSCs consist of metal plates, with a spectrally sensitive surface, which absorb solar radiation, raising their temperature. The plates are attached to a south facing (in the northern hemisphere), vertical wall of a building, such as to leave a small air gap, and sealed at the edges, to form a plenum i.e. a thin box, or cladding. The collector plate is perforated with many small holes drilled in its surface, through which ambient air is drawn, by a small fan, into the plenum. There, the air is heated by convection from the collector plate, increasing its temperature by up to 25 K. The heated air flow can then be used e.g. for space heating or for pre-heating hot water within the building. The air temperature increase achieved depends on the environmental conditions, the solar collector plate design e.g. distribution of perforations and surface coating, and the air flow rate and face velocity of the air at its surface. The coatings used by the current generation of TSCs are generally of high emissivity, which although achieving high absorption of solar radiation, are also subject to high radiation heat losses to the outside environment. However, new spectrally selective, low emissivity (low-ε) coatings have been developed, which enable the collector's absorptivity to be maintained, while minimizing re-radiation to the environment. This results in higher collector plate surface temperatures and generates higher output air temperatures.

TSCs generally form part of a building's cladding and due to their simple, unglazed construction can be installed at low additional costs relative to standard claddings, often with a marginal cost of below £50 per m^2. Installations have typically achieved simple paybacks of less than 7 years. The paper reports the results of an investigation by computer modelling of the potential of low-ε TSCs to provide solar enhanced heated air for delivery to buildings via ventilation systems. The increase in air temperatures obtained from the TSC varies with the solar radiation available i.e. from minute to minute, as well as daily and seasonally, and is only available during the day. Therefore, for an effective heating system, the TSC needs to be combined with another heating system which can be used to meet the building heat demand at other times. In this study, the heated air generated by the TSC has been used as a heat source for an air source heat pump, which is then used to meet the space heating demand profile of a building. A number of configurations for combining the TSC with the heat pump have been evaluated, and compared to the case, where the TSC is not used, to investigate its potential benefits. Traditional (high- ε) TSCs have been combined with ventilation air heating systems and evaluated previously e. g., and the present authors have reported the use of low-ε TSCs with ventilation heating systems applied to a domestic house, and a warehouse. However, the current study evaluates the effect of building size, comparing small and large buildings, and investigates the effect of environmental conditions on the performance of the TSC, by applying the model at a wide range of locations.

Methodology

The evaluation of the performance of a number of configurations of TSC-heat pump building heating systems was undertaken using a modelling approach, employing Engineering Equation Solver (EES), a commercial software tool. The performance of the overall heating system was simulated using a series of simultaneous equations to define the relationships between the parameters needed to describe the system. Input data for parameter values e.g. temperatures, fluid flow rates and thermal properties, were provided, and the software used to predict a number of unknown parameter values, such as the total electrical energy input to the system and the efficiency for the heat pump. In fact, to simplify the solution process, the overall heating system was divided into a number of component modules, which were then solved in sequence, in order to evaluate the overall performance of the system. The components included: (i) a TSC model; (ii) a building heat demand model; (iii) a heat pump model; (iv) a control model. The control model was needed to define the order for solving the various component models, and to switch the heat pump on and off, as required, for different input conditions. Details of the various component models are provided in the following sections.

Transpired solar collector (TSC) model

In this study, the heated air generated by the TSC device was ducted to a building, either to provide heated ventilation air directly, or to be used as a heat source for a heat pump. There was also a bypass opening in the TSC to permit ambient air to be used directly for ventilation, when solar heated air was not required. The volumetric air flow rate through the TSC was set equal to the ventilation air flow rate, which was calculated in the building heat demand model.

In earlier studies, it was found that a collector plate face velocity in the range 0.02–0.05 m/s was needed for effective operation of the TSC. By using the volumetric air flow rate through the TSC and dividing by the face velocity at the surface of the collector plate (selected to be 0.021 m/s for the current model), the required collector plate area could be calculated. In each case, the collector plate area was estimated to be substantially less than the available area of the selected building wall.

In an earlier study, it was found that an air temperature increase of 20 % could be obtained using a spectrally sensitive low emissivity coating for the collector plate compared with high emissivity plates, for the same absorptivity surface. For each of the models in the current study, a surface absorptivity of 0.9 and an emissivity of 0.2 were assumed. Further details of the TSC model have been provided previously. A schematic of a transpired solar collector together with the energy balance at the collector plate surface is shown in Fig. 1.

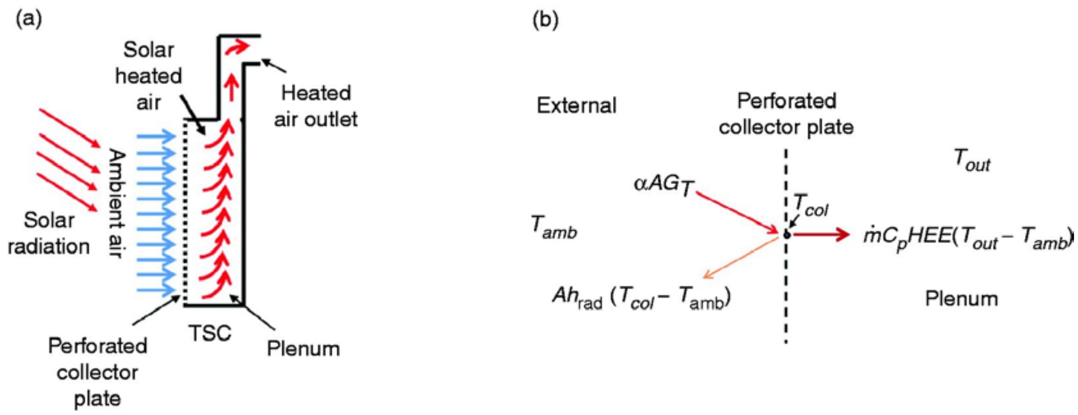

Figure 1. Transpired solar collector (TSC) (a) Schematic of TSC; (b) Energy balance at collector plate surface

In Fig. 1(b), α is the absorptivity of the solar collector plate surface, A is the area of the plate, G_T is the solar global radiation per unit area, h_{rad} is the linearized radiation heat transfer coefficient, which also incorporates the emissivity of the surface, and T_{col} is the temperature for the solar collector surface. On the inside of the enclosure, m is the mass flow rate of the air, which enters at ambient temperature T_{amb}. C_p is the specific heat capacity of the air flowing through the enclosure, and T_{out} is the temperature of the air at the outlet. HEE is a heat exchange effectiveness coefficient which takes account of the convective heat transfer from the collector plate to the air. The pressure drop through the collector plate was determined using a scaling factor used to model square pitch perforations. The energy balance for the collector plate is shown in equation (1)

$$\dot{m}CpHEE(Tcol-Tamb) = \alpha AGT-Ahrad(Tcol-Tamb)$$

The heat exchange effectiveness coefficient (HEE) is defined by equation (2)

$$HEE = \frac{(\,T_{out} - T_{amb})}{(T_{col} - T_{amb})}$$

In equation (1), the main (variable) inputs needed were weather data parameters e. g. for air temperatures and solar radiation. These were obtained from a weather database, for a location in the London Borough of Islington, which had been selected as a potential trial site for a prototype system. The weather data consisted of hourly values for ambient air temperature, ground temperature, sky temperature, air pressure, relative humidity, wind speed, global radiation on a south-facing vertical plane and global radiation on a horizontal plane. The overall mass air flow rate $\dot{m}\dot{m}$ through the TSC was determined from the building heat demand model. The TSC model was then used to calculate the hourly variation in the solar collector output air temperatures.

Building heat demand model

A building model was developed to estimate the building space heating demand to be met by the heating system employed. It consisted of a simple air ventilated building, subject to heat losses through the building fabric due to the difference between the internal set temperature and the seasonal variation in outside environmental conditions, and heat losses from the exhaust ventilation air leaving the building at the internal building set temperature. To maintain the set temperature within the building, it was assumed that the required quantity of heat was added via the ventilation air supply, by raising its temperature, as appropriate. The ventilation air mass flow rate was calculated, based on the internal volume for the building and number of air changes per hour selected. The heated ventilation air supply at the appropriate temperature was generated using an air source heat pump, and supplemented by the TSC heated air. When the TSC heated air temperature reached the ventilation air temperature indicated from the building heat demand model, the heat pump could be switched off and the heated ventilation air supplied by the TSC alone.

The building model assumed the building to be a rectangular box, with no internal structure, and to be heated by a single ventilation air heating system to a common temperature throughout. Two building sizes were considered, namely a small domestic building e.g. a house, and a large warehouse building. To calculate the heat demand for the building (at any particular time), the following assumptions were used: In Table 1, the ventilation exhaust heat loss coefficient was calculated as the product of the mass flow rate of exhaust air and specific heat capacity.

Table 1 – Building heat demand model parameters used

Parameter	Value (Domestic house)	Value (Warehouse)
Building dimensions (m) Volume (m^3)	10 10 1000	44.72 44.72 20 40,000
Single internal space i.e. no internal structure was considered, for the purposes of the model	–	
Ventilation rate (air changes per hour)	2	
Building internal set temperature T_{set} (C)	22	
Fabric heat losses i.e. through the walls, floor, roof, windows and doors, were defined by their overall heat transfer coefficient U and area A values, and these together with the ventilation exhaust heat loss coefficient, were compounded into a single heat loss coefficient HLC (W/K)	860	30,168
Building fabric U values[15] (W/m^2 K) Walls	0.18	
Floor	0.13	
Roof	0.13	
Windows and doors	1.4	
% of front and back walls (only) occupied by windows and doors	40	
Ventilation air mass flow rate (kg/s)	0.56	26.6
Specific heat capacity (J/kg K)	1019	
Temperature difference DT between the inside building, air set temperature T_{set} and outside ambient air temperature T_{amb} (K)	Tset-Tamb	
Total heat loss for the building (equal to the total building heat demand) Q_{demand} (W)	HLC DT	

Using the assumptions in Table 1, and hourly ambient air temperatures, the model was used to determine the seasonal heat demand profile for the building.

Heat pump model

The heat pump model was simulated as a single stage air source heat pump using a series of thermodynamic balance equations to link the input and output parameters and performance of each of its components. Input data for the various components were specified for the model, and the equations then solved iteratively to predict selected outputs and the overall performance of the heat pump. The model comprised three main component sub-models, namely a single stage compressor, and finned tube air to refrigerant evaporator and condenser heat exchanger models. The condenser heat output capacity (which was matched to the hourly varying building heat demand) was used as input for the heat pump model, which then predicted the compressor swept volume and the electrical energy input to the compressor. It was assumed that a variable speed compressor was used, such that the capacity of the heat pump could be varied in line with the building heat demand, in order for the heat pump to take advantage of the rapidly varying input air temperature conditions provided by the solar collector output. Key inputs for the heat pump model were: (i) the condenser output capacity required; (ii) the condenser output air temperature needed; (iii) the TSC output air temperature; (iv) the volumetric flow rate for the air over the heat exchangers, which was defined by the ventilation air flow rate required for the building; (v) the condenser air on temperature, which for some configurations was ambient air, and for others was TSC heated air (vi) the evaporator air on temperature, which for some configuration options was ambient air, and for others was TSC heated air, or the exhaust air from the building (i.e. enabling it to operate as an exhaust air heat pump). When the TSC heated air temperature was greater than the ventilation air temperature needed, while the ambient air temperature was less than the required ventilation air temperature, it was assumed that the TSC heated air could be mixed with the ambient air to produce the required air temperature, and used directly for the ventilation air supply. In this case, the heat pump would be switched off.

Control model

A key requirement for the operation of the heat pump sub-model within the overall TSC-air source heat pump-ventilation air heating system model, was a control sub-model. This was used to determine whether the heat pump was switched on or off at any particular time/set of input conditions, and to read the key parameter inputs for the heat pump model, from the building heat demand and TSC models. It was also used to provide appropriate guess values for iterative solving of the equations defining the heat pump model, in order to facilitate convergence. In addition, it controlled the sequence for execution of each of the sub-models i. e. the building heat demand model, TSC model, and heat pump model. At any particular time (i.e. time step), the heat required to meet the building heat demand could be derived from several sources, namely: (i) directly from the TSC output air flow; (ii) after upgrading the TSC output air temperature with the heat pump; (iii) directly from the outside ambient air. It was therefore necessary to provide a control algorithm for selection of the most appropriate heat source. A further consideration was that in some cases, very large temperature differences between the ventilation inlet air and the internal building air temperature were needed to meet the highest building heat demands, and this was undesirable with respect to the thermal comfort level within the building. Therefore, the temperature difference between the ventilation inlet air delivered $T_{delivery}$ and the building air set temperature T_{set} was limited to 8 K. This was also accounted for in the control model. If more heat was needed to meet the building heat demand than could be achieved by the ventilation air, with this limited temperature difference (and since the ventilation air flow rate was fixed), it was assumed that the difference in heat capacity was made up by an electric heater (with 100 % efficiency) located within the building. The cost and carbon emissions associated with this additional electricity input needed to meet the building heat demand were also calculated, and added to the totals for energy, carbon and cost inputs for the heating system.

Ventilation heating system configurations modelled

In Fig. 2, TSC is the transpired solar collector and HP is an air source heat pump. The four heating system configurations shown were each modelled with: (i) the TSC in operation; and (ii) in bypass mode, where ambient air only was provided.

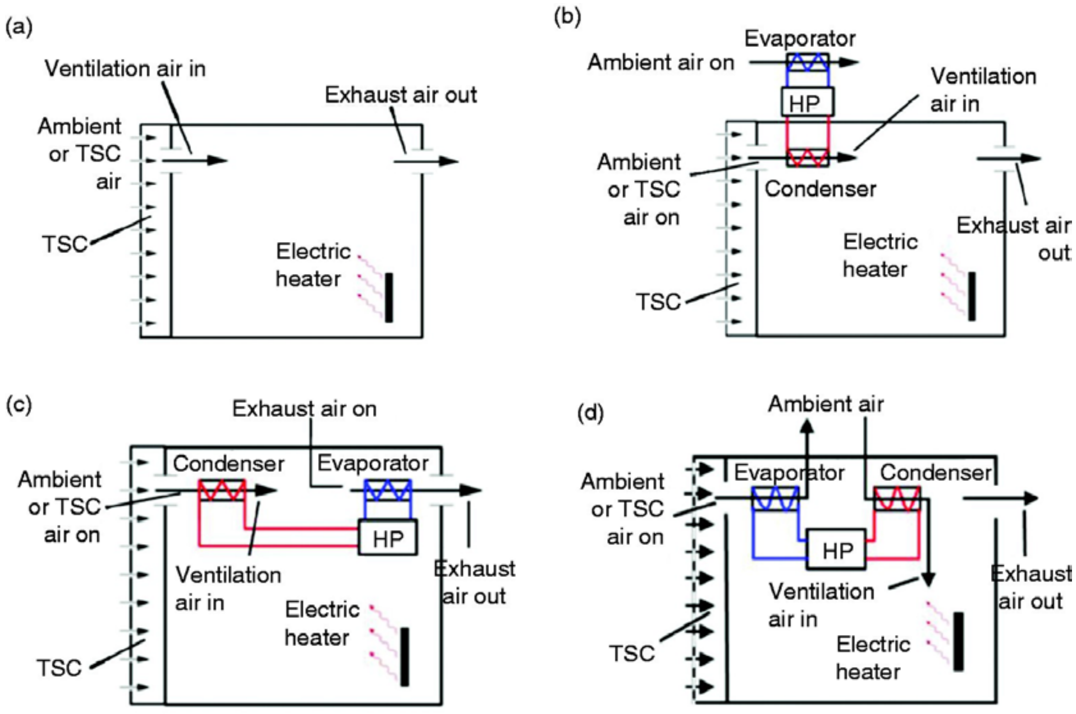

Figure 2. Ventilation air heating system configurations modelled. (a) Electric heating of building only; (b) Heat pump with ambient or TSC air onto condenser, ambient air onto evaporator, and electric heater top-up; (c) Heat pump with ambient or TSC air onto condenser, exhaust air onto evaporator, and electric heater top-up; (d) Heat pump with ambient air onto condenser, ambient or TSC air onto evaporator, and electric heater top-up

For the three configurations using heat pumps shown in Fig. 2, where either the ambient air or TSC heated air temperatures reached or exceeded the building heat demand ventilation air temperature required, the heat pump was assumed to be switched off within the model.

Results

The results from the modelling work are presented in the following sections.

TSC model

TSC heated air temperatures

Fig. 3 shows the results for seasonal variation in TSC heated air output temperatures in comparison with ambient temperatures, predicted by the model.

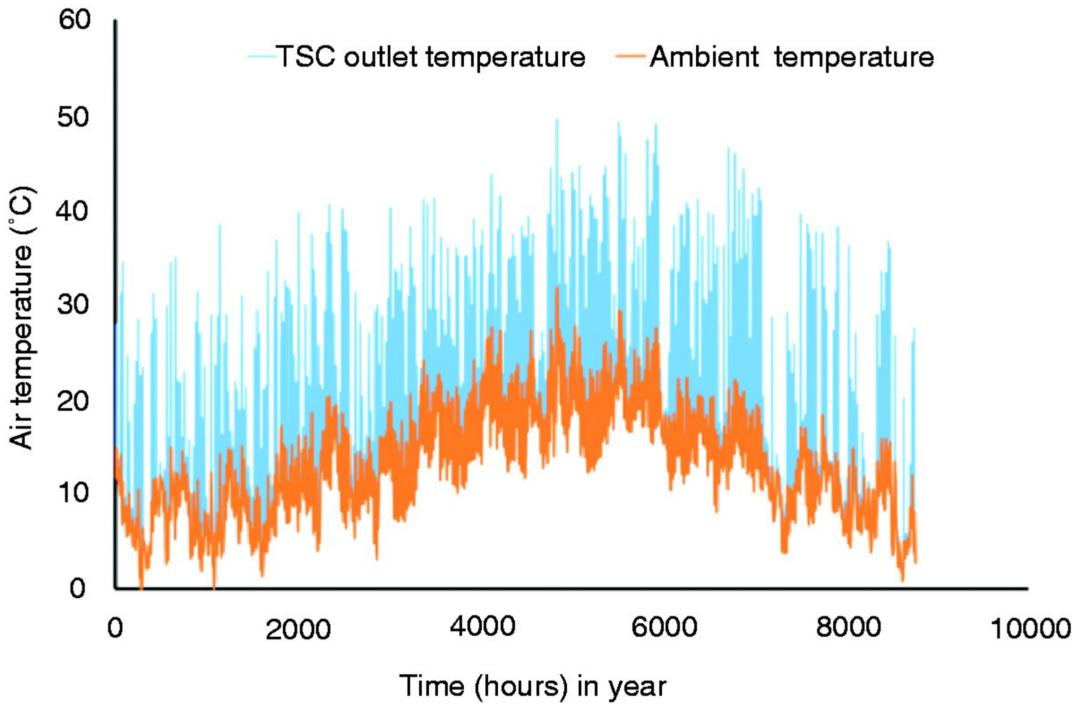

Figure 3. Annual temperature profile for TSC outlet air for London location

It is seen that there was a significant increase in temperature for the TSC outlet air compared to ambient air, of up to 25 K, however, the TSC outlet air temperature increase varied significantly (in the range 0–25 K) from hour to hour. It should be noted that the air temperature profiles both with and without the TSC were effectively identical for the small (domestic) building and large (warehouse) building.

Rise in air temperatures in TSC

A comparison of the rise in air temperatures in the TSC for the four different locations considered, namely London, New York, Stockholm and Southwest Florida is shown in Fig. 4.

The profiles for temperature rise in the TSC were distinctly different for the four different locations. In most cases the maximum temperature rise in the TSC was of the order of 25 K, although some slightly higher temperature rises of up to 28 K were seen for the New York location, in winter. For the London location, temperature rises were of the order of 20–25 K for most of the year, but were reduced to approximately 16–18 K for about 1000 h in the middle of summer. The temperature rise profile in the TSC for the Stockholm location also showed increases of 20–25 K for most of the year, but with no reduction in summer.

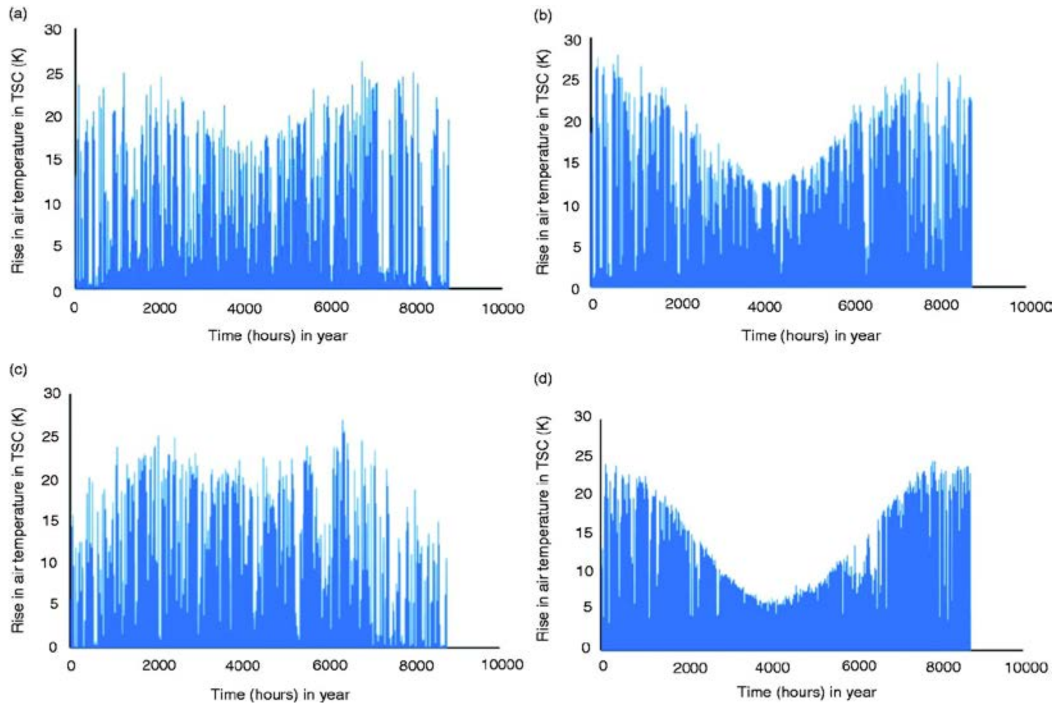

Figure 4. Temperature rise in TSC at four locations. (a) London; (b) New York; (c) Stockholm; (d) Southwest Florida

However, the Stockholm location showed reduced temperature rises of 12–15 K for approximately 1000 h in the middle of winter. In contrast, for the two USA locations i.e. New York and Southwest Florida, the temperature rise in the TSC was highest in winter, but decreased steadily to a minimum in the middle of summer. The minimum temperature rise in the TSC for the New York location was approximately 14 K, while for the Southwest Florida location it was approximately 7 K.

Comparison of small (domestic) building and large warehouse building

The annual building heat demand profile for the small and large buildings considered, both for the London location, are presented in Fig. 5. The figures show the daily variation in heat demand for each building in kWh, over a year. The heat demand values predicted by the model are based on the ventilation air mass flow rate, the set temperature selected for the building, and weather data, and depend particularly on the outside, ambient air temperatures.

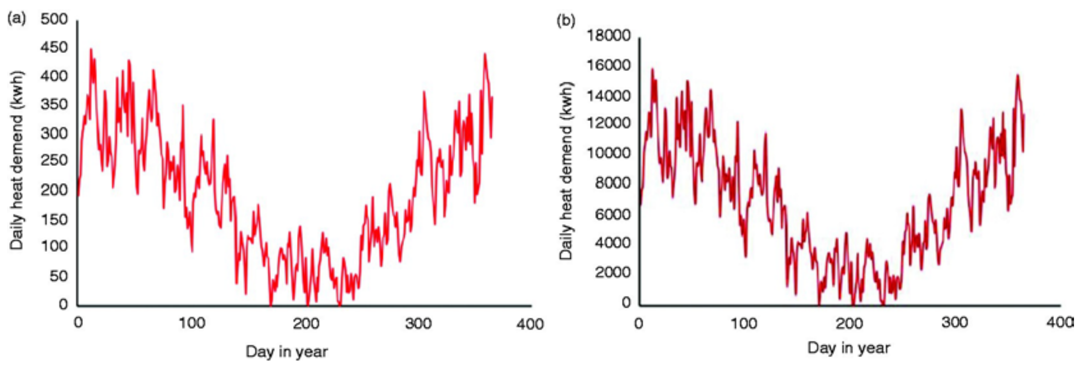

Figure 5. Seasonal variation in building heat. (a) Small domestic building (house); (b) Large building (warehouse)

In Fig. 5, the daily heat demand, follows a sinusoidal trend over the year, with the highest heat demand, of approximately 400 kWh per day for the small domestic building and 16,000 kWh per day for the large warehouse building occurring during the winter months. In each case, the heat demand then decreases to a minimum level of 0 kWh at times during the summer months, although varying by up to 100 KWh for the small building and 4000 kWh for the large building from day to day, throughout the year.

The building heat demand models were used to predict the temperatures needed for the ventilation air supplied to the building, in order to replace all of the heat losses from the building i.e. to match the heat demand value, on an hourly basis, throughout the year.

Comparison of building heat demand profile at four locations

A comparison of the building heat demand profiles for the large warehouse building at the four locations considered, namely London, New York, Stockholm and Southwest Florida are shown in Fig. 6.

Comparing the building heat demand profiles for the four locations, on an hourly basis, for the large (warehouse) building, using the same axis scaling for each graph, showed some distinct differences. For the London location, the hourly building heat demand varied sinusoidally from a maximum of 600 kWh in winter to a minimum of 0 kWh, at times, in summer, although with an average heat demand of approximately 100 kWh for 2200 h i. e. three months, in summer.

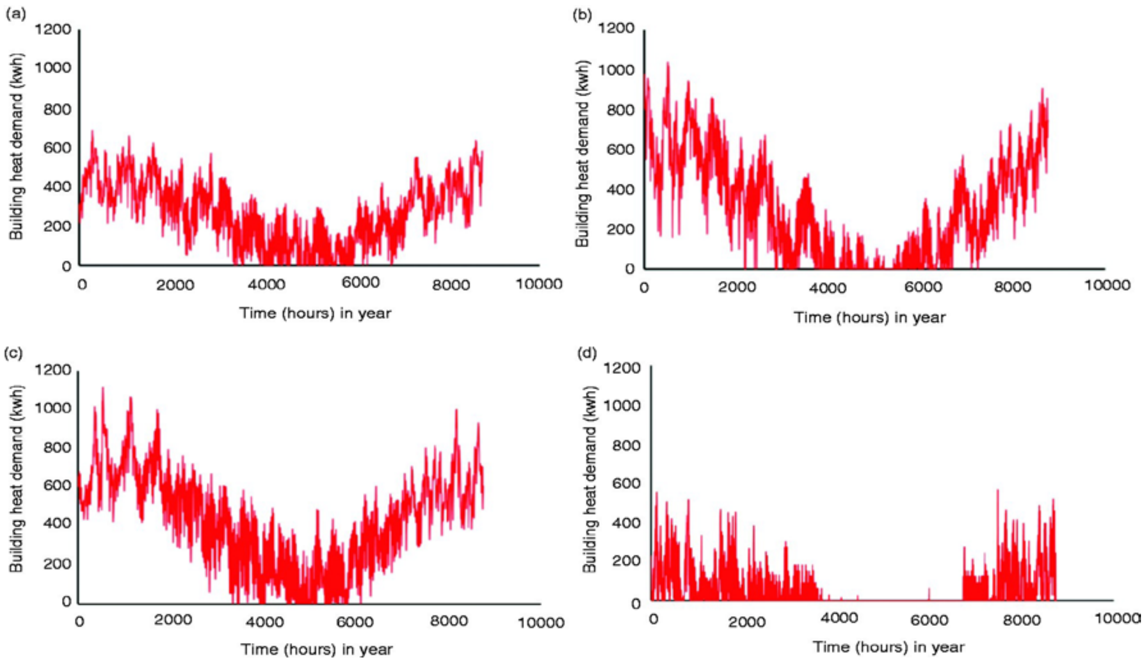

Figure 6. Comparison of building heat demand profiles for warehouse building for four different locations. (a) London; (b) New York; (c) Stockholm; (d) Southwest Florida

In contrast, for the New York location, a larger amplitude sinusoidal variation was seen, with a maximum building heat demand of 1000 kWh in winter decreasing to a minimum of 0 kWh in summer, with an average heat demand of 0 kWh for 1500 h

i. e. 2 months, in summer. For the Stockholm location, a building heat demand profile combining parts of both the London and New York profiles is seen, with a maximum of 1000 kWh in winter, a minimum of 0 kWh in summer, but with an average heat demand of approximately 150 kWh for 2200 h i. e. 3 months, in summer. The Southwest Florida location shows a much lower heat demand than for the other locations, with a maximum of 500 kWh in winter, but zero heat demand for 3000 h i. e. 4 months, in summer.

Results for heat pump model and analysis

A summary of the heating system configurations considered is shown in Table 2.

Table 2 – Air ventilation heating system configurations

Configuration	Description
1	Electric heater only
2	Heat pump heating, TSC or ambient air onto condenser, ambient air only onto evaporator
3	Heat pump heating, TSC or ambient air onto condenser, building exhaust air onto evaporator
4	Heat pump heating, ambient air only onto condenser, TSC or ambient air onto evaporator

The outputs from both the TSC model and building heat demand model, together with hourly ambient air temperatures, derived from the weather data, were used as inputs for the heat pump model. The model was then used to determine the total electrical energy needed to supply both the heat pump compressor and heat exchanger fans, together with any additional top up by the electric heater if required, in order to meet the required heat output capacity and ventilation air delivery temperature.

The overall electrical energy used by the ventilation air heating system was then used to calculate the corresponding CO_2e emissions and estimated cost for the electricity, for each of the configurations considered both with and without the TSC heated air in operation. Assumptions used in calculating the carbon dioxide equivalent (CO_2e) emissions and costs were: (i) an electricity carbon factor of 0.2555 kg CO_2e per kWh of electricity used; and (ii) a cost for electricity of £0.155 per kWh of electricity.

Comparison of performance of four heating system configurations for small domestic building

A comparison of the results for electrical energy input, CO_2e emissions and costs for the four heating system configurations for the small, domestic building, at the London location, are shown in Fig. 7.

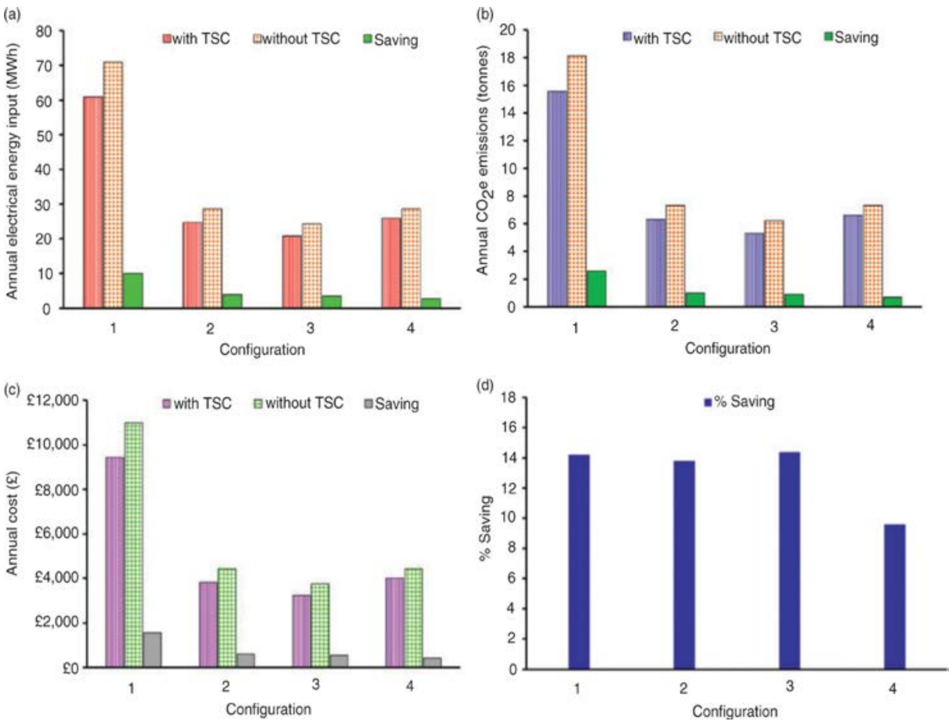

Figure 7. Energy, carbon emissions and cost savings with TSC for four heating system configurations for small, domestic building (house), located in London, UK. (a) Annual electrical energy input; (b) Annual CO2e emissions; (c) Annual costs; (d) % Saving

It is seen in Fig. 7 that the heating system configuration with the lowest electrical energy use, CO_2e emissions and costs was configuration 3 i. e. the exhaust air heat pump. This system also demonstrated a further benefit of an additional energy, emissions and cost saving of 14.4 % from using the TSC device. The electrical heating only system (configuration 1) showed similar % savings when using the TSC, however, its overall energy use was much greater i.e. of the order of three times that of the heat pump-based heating systems (configurations 2, 3 and 4). Considering the other two heating system configurations, for configuration 2, the standard heat pump system with TSC heated air directed onto the condenser, the energy input was a little higher than for the exhaust air heat pump (configuration 3), and the % saving with the TSC marginally lower i. e. 13.8 %. However, for configuration 4, the standard heat pump with TSC heated air directed onto the evaporator, while the energy input was similar to configuration 2, the % saving with the TSC was significantly lower i. e. 9.6 %.

Comparison of performance of four heating system configurations for large warehouse building at four locations

The four heating system configurations at the four locations considered i. e. London, New York, Stockholm and Southwest Florida were compared, for the large warehouse building. The results for annual electrical energy input for each heating system configuration at the four locations are shown in Fig. 8. It is seen in Fig. 7 that the heating system configuration with the lowest electrical energy use, CO_2e emissions and costs was configuration 3 i. e. the exhaust air heat pump. This system also demonstrated a further benefit of an additional energy, emissions and cost saving of 14.4 % from using the TSC device. The electrical heating only system (configuration 1) showed similar % savings when using the TSC, however, its overall energy use was much greater i.e. of the order of three times that of the heat pump-based heating systems (configurations 2, 3 and 4). Considering the other two heating system configurations, for configuration 2, the standard heat pump system with TSC heated air directed onto the condenser, the energy input was a little higher than for the exhaust air heat pump (configuration 3), and the % saving with the TSC marginally lower i.e. 13.8 %. However, for configuration 4, the standard heat pump with TSC heated air directed onto the evaporator, while the energy input was similar to configuration 2, the % saving with the TSC was significantly lower i. e. 9.6 %.

Comparison of performance of four heating system configurations for large warehouse building at four locations

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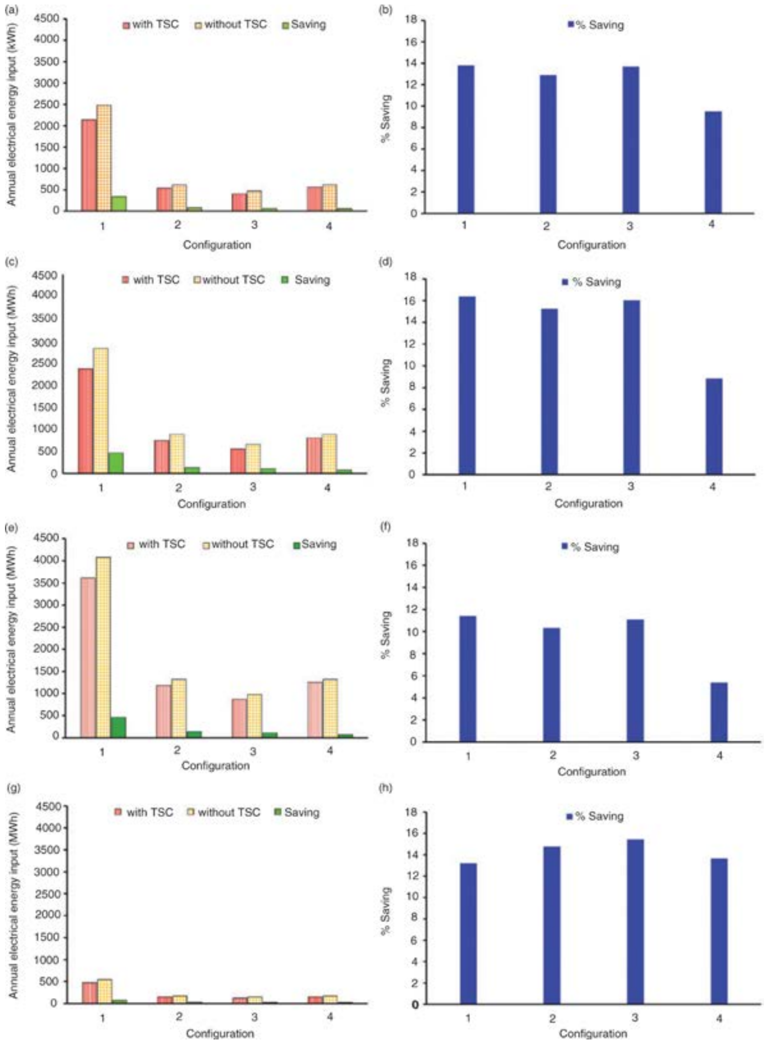

Figure 8. Annual electrical energy inputs and % Saving for four heating system configurations for warehouse building at four locations. (a) Annual electrical energy – London; (b) % Saving – London; (c) Annual electrical energy – New York; (d) % Saving – New York; (e) Annual electrical energy – Stockholm; (f) % Saving – Stockholm; (g) Annual electrical energy – Southwest Florida; (h) % Saving – Southwest Florida

It is seen in Fig. 8, that the pattern of annual electrical energy input values for the four heating system configurations was the same for all four locations. In each case, the highest electrical energy input was for the electric heating only system (configuration 1), however, significantly lower but similar electrical energy inputs were calculated for the two standard heat pump systems (configurations 2 and 4). The lowest electrical energy input for all locations was the exhaust air heat pump (configuration 3). The greatest % saving with the TSC was also for configuration 3, at each location, although a similar high % saving was achieved for the electrical heating only system i.e. configuration 1, for the first three locations (Fig. 8b, d and f). A marginally lower % saving with the TSC for configuration 1 compared to configuration 3 was observed for the Southwest Florida location (Fig. 8h). The highest % saving with the TSC i. e. 16.1 % was achieved for configuration 3 for the New York location. The % saving with the TSC was also high i. e. 15.4 % for configuration 3 for the Southwest Florida location, although the annual electrical energy inputs for this location were much lower than for the other three locations. For the Stockholm location (Fig. 8e and f), the % saving with the TSC for configuration 3 was a little lower i. e. 11.1 %. Due to the relatively high room temperature setting selected for the building model i. e. 22 °C, it is seen in Fig. 6a and c, there is some heat demand throughout the year for the London and Stockholm locations. In practice, space heating might not be used during the summer months, and the building temperature allowed to fluctuate with the ambient temperature at this time. Therefore, these models have been re-run with the assumption of a heating season of 7 months only for the London and Stockholm locations, with no heat input for 5 months of the year. Under these conditions, although the annual heat demand was reduced, the relative performance of the different heating system configurations remained the same. However, there was a reduction in the % saving when using the TSC of approximately 2 %, in each case, highlighting the potential benefits of employing the TSC during the summer months. Therefore, although there are still substantial benefits from employing the TSC for a 7-month heating season only, there is also a case for utilizing the heat output of the TSC for e.g. domestic water heating or thermal storage during the summer, to take advantage of the solar gain over this period. Although only the annual electrical energy inputs for each heating system are reported here, since the annual CO_2e emissions and costs were calculated from the annual electrical energy input values for each configuration, the % savings with the TSC were the same, in each case.

TSC heated air temperatures

The TSC outlet seasonal temperature profile shown in Fig. 3 follows a similar pattern to that for ambient temperatures, although with increased temperatures of between 0 and 25 K. A similar level of increase in TSC outlet temperatures above ambient is seen throughout the year. There are, however, significant differences in TSC output temperatures from hour to hour, reflecting the variation in solar radiation availability. In fact, the performance of a TSC can be reduced in buildings with an early morning or late evening dominated heating demand, since a large proportion of the heating demand will be at a time when there is little or no solar radiation available.[5] In this case, the performance i. e. % saving, with the TSC could be improved by incorporating thermal storage, to store heat generated in excess of demand during the middle of the day, and then using it in the early morning/late evening or at night. It has been previously observed, that factors affecting the TSC absorber plate thermal efficiency include irradiance, air flow rate through the TSC, outside air temperature, wind speed and direction.

Rise in air temperatures in TSC

The rise in air temperatures in the TSC for the four locations considered (Fig. 4) show some distinct differences in variations in temperature rise through the year. In each case, the maximum rise was of the order of 20–25 K, which was in line with the maximum expected for the TSC based on previous studies. In general, the highest temperature rises occurred in the winter months, with reduced temperature rises during the summer months. This probably reflects the fact that it is easier to generate a temperature difference between the TSC solar collector plate and the ambient air in winter. It is apparent, however, that there is a concentration of the number of hours at which a temperature rise was observed in summer, so the overall solar collection is likely to be greater at this time. One exception to the general trend is for the Stockholm location (Fig. 4c), which showed slightly lower temperature rises during the winter months. This may be due to the more northerly latitude of Stockholm compared to the other locations, whereby the global solar radiation is marginally reduced in winter.

Comparison of small and large buildings

The seasonal building heat demand profiles in Fig. 5a and b show a clear annual trend i. e. higher heat demand in winter and much reduced demand during the summer months, although with significant day to day variation. The building heat demand effectively mirrors the seasonal variation in ambient temperatures, and follows a typical seasonal pattern for heat demand in buildings. The building heat demand profiles were effectively identical for the small domestic building and large warehouse building, at the London location, although with proportionally higher heat demand for the larger building. The building heat demand model was used to calculate the hourly variation in ventilation air temperatures to be supplied to the building in order to meet demand, and these were used as input for the heat pump model.

Comparison of building heat demand profiles at four locations

The building heat demand profiles for the large warehouse building at the four locations considered are shown in Fig. 6, and demonstrate some significant differences. The greatest seasonal variation in building heat demand was for the New York location (Fig. 6b). A slightly lower seasonal variation was found for the Stockholm location, although with increased heating demand in summer compared to the New York location. For London, there was a much smaller seasonal variation in building heat demand than for the New York and Stockholm locations. The lowest overall heat demand was for the Southwest Florida location, with no heat requirement at all for 4 months in summer. The building heat demand profiles observed reflect the different environmental (weather) conditions for the four locations, particularly seasonal variation in ambient air temperatures and solar radiation.

Comparison of performance of four heating systems for small building

The annual electrical energy input, CO_2e emissions and costs for the four heating system configurations both with and without the TSC included, for the small building, are shown in Fig. 7. The electric only heating system (configuration 1) indicated the highest values for each parameter (i.e. electricity input, CO_2e emissions and costs) and therefore was the least useful and least economic of the four heating systems considered. However, configuration 1 demonstrated high potential savings of 14.2 % when the TSC was used. The three-heat pump-based heating systems all required much lower electrical energy inputs which resulted in much lower CO_2e emissions and costs i. e. approximately one-third that of the electric only heating system. The best performing system with the lowest electrical energy input requirement (and lowest CO_2e emissions and costs) was the exhaust air heat pump (configuration 3). Configuration 3 also demonstrated the highest % saving of 14.4 % when the TSC was used. For the other two heating systems i. e. configurations 2 and 4, reduced savings when using the TSC of 13.8 % and 9.6 % respectively were determined by the model. In the case of configuration 2, TSC heated air was directed onto the condenser and ambient air onto the evaporator. However, for configuration 4, TSC heated air was directed onto the evaporator and ambient air onto the condenser. Therefore, the most effective way of utilizing the TSC heated air with a heat pump-based air ventilation heating system is by directing it onto the condenser.

The model was also used to evaluate the performance of the large, warehouse building at the London location. Similar patterns of energy use, CO_2e emissions and costs, were found, although with proportionally higher values for each parameter for the larger building. The % saving when using the TSC was also similar for the warehouse building, although marginally lower i. e. 13.7 % for configuration 3, compared to 14.4 % for the small building.

Comparison of four heating system configurations at four locations

A comparison of the performance of the four heating system configurations for the four locations considered, namely London, New York, Stockholm and Southwest Florida are shown in Fig. 8. The relative performance of the heating systems was the same for each location i. e. with configuration 3 (the exhaust air heat pump) performing best, followed by the other two heat pump based systems (configurations 2 and 4), with the electric only heating system (configuration 1) being the most energy intensive and having the highest emissions and costs. In terms of benefit i. e. % saving, from using the TSC, the exhaust air heat pump (configuration 3) again performed best, at each location. The highest % (annual) saving when using the TSC was 16.1 % for the New York location. This compared with a % saving for the Southwest Florida location of 15.4 %, for London of 14.4 % and Stockholm of 11.1 %. It is considered likely that the % annual savings with the TSC determined for the different locations reflects the seasonal availability of solar radiation at these locations, and this is largely dependent on their latitudes. Considering three of the locations only i.e. New York, London and Stockholm, in terms of their latitudes; New York has the lowest latitude of 41°N, London has a latitude of 51°N, and Stockholm a latitude of 59°N, and this corresponds to the order of % savings with the TSC at these locations. An exception to this trend is the Southwest Florida location which has the lowest latitude of all i. e. 26°N, so would be expected to obtain the greatest benefit from the TSC i. e. highest % saving. However, the overall building heat demand was very low for Southwest Florida compared to the other three locations, and for 4 months in the summer (when solar radiation availability was greatest) no heat was required. Consequently, there was less opportunity for the

TSC to enhance the four heating systems, so may explain why the % saving was a little lower than would be expected in relation to its latitude.

Conclusions

This study has investigated the effects of using a low-ε TSC device to generate heated air, when incorporated into a range of configurations of ventilation air space heating systems for buildings. The configurations evaluated included an electric heating only system and three heat pump-based heating systems, both with and without the TSC included. Using models, the effects of building size and environmental conditions, at a range of locations have been investigated. The electrical energy input, CO_2e emissions and operating costs were determined for each configuration.

In each case, the electric heating only system required very high energy input, resulting in high CO_2e emissions and costs i.e. by more than three times that for any of the heat pump based systems, for the small, domestic building (Fig. 7), and by more than four times for the large, warehouse building, for the London location . For both the small and large buildings and for all locations, the best performing system i.e. that with the lowest electrical energy input, CO_2e emissions and costs was configuration 3, the exhaust air heat pump. Significant additional savings were achieved for all heating system configurations i.e. both the electric only and heat pump-based systems, for both building sizes and at all locations, when the TSC was used, with values (for configuration 3) ranging from 11.1 % to 16.4 %. In each case, the greatest % saving was for configuration 3 i. e. the exhaust air heat pump, with savings of 14.4 % and 13.7 % for the small and large buildings respectively, for the London location. However, the greatest saving when using the TSC was 16.4 % for configuration 3, for the large warehouse, at the New York location, although very significant savings were achieved at all of the locations considered. However, it was concluded that, in general, the % saving with the TSC increased with decreasing latitude, with increasing % savings in the order Stockholm, London and New York. The exception to this was the Southwest Florida location which had the lowest latitude of all, but indicated the second highest % saving. It was concluded that this location was anomalous due to having a very low annual heat requirement, and having zero building heat demand for 4 months during the summer (and the heating system was switched off), when solar radiation availability was at its maximum.

The results for the three-heat pump-based systems i.e. configurations 2, 3 and 4, for both the small and large buildings, and for all locations, were compared. It was seen that when the TSC heated air was directed onto the condenser i.e. configurations 2 and 3, significantly higher % savings were achieved than for configuration 4, when the TSC heated air was directed onto the evaporator. Therefore, in order to maximize the benefit obtained from the TSC for a heat pump-based air ventilation heating system, the TSC heated air should be directed onto the condenser. Other potential benefits of using TSCs are that they can act as cladding for buildings, providing extra insulation, and reducing fabric heat losses. In future work, it is planned to investigate the use of low-ε TSCs in other building heating system configurations. Also, the use of low-ε TSCs with other building types and for pre-heating of hot water for buildings, and for combining with storage systems to provide better utilization of the TSC generated heat will be investigated.

Overall, it is concluded that low-ε TSCs offer significant benefits in providing low cost, low carbon heating for buildings.

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Words and word combinations:

– exhaust [ɪgˈzɔːst] – выхлоп;
– respectively [rɪˈspektɪvli] – соответственно;
– demonstrated [ˈdem.ən.streɪt] – продемонстрировал;
– ventilation [ˌven.tɪˈleɪ.ʃən] – вентиляция;
– emissions |ɪˈmɪʃənz| – выбросы;
– assumption [əˈsʌmp.ʃən] – предположение;
– considered [kənˈsɪd.əd] – обдуманный;
– performing [pəˈfɔːm] – выполнение;
– incorporated [ɪnˈkɔː.pər.eɪ.tɪd] – включены;
– evaporator [ɪˈvæpəreɪtə] – испаритель;
– concluded [kənˈkluːd] – заключил;
– proportionally [prəˈpɔː.ʃən.əl] – пропорционально;
– latitude [ˈlæt.ɪ.tjuːd] – широта;
– employing [ɪmˈplɔɪ] – использование;
– determined [dɪˈtɜːmɪnd] – определенный;
– environmental [ɪnˌvaɪrənˈmentl] – относящийся к окружающей среде;
– condenser [kənˈden.sər] – конденсатор;
– absorptivity [əbˈzɔːpʃ(ə)n] – поглощающая способность;
– identical [aɪˈden.tɪ.kəl] – идентичный;
– upgrading [ʌpˈgreɪd] – обновление.

Task 2. Summarize all the ideas of the article and write an essay.

Task 3. Make a presentation based on the article.

ЧАСТЬ IV. БЕСЕДА ПО СПЕЦИАЛЬНОСТИ

Summary

Task 1. Read the following instructions offered by Virginia Kearney, a university expert in writing essays (https://owlcation.com/academia/How-to-Write-a-Summary-Analysis-and-Response-Essay, 05.2019).

A summary is telling the main ideas of the article in your own words.

Steps in Writing

These are the steps to writing a great summary:

1. Read the article, one paragraph at a time.
2. For each paragraph, underline the main idea sentence (topic sentence). If you can't underline the book, write that sentence on your computer or a piece of paper.
3. When you finish the article, read all the underlined sentences.
4. In your own words, write down one sentence that conveys the main idea. Start the sentence using the name of the author and title of the article (see format below).
5. Continue writing your summary by writing the other underlined sentences in your own words. Remember that you need to change both the words of the sentence and the word order.
6. Don't forget to use transition words to link your sentences together. See my list of transition words below to help you write your summary more effectively and make it more interesting to read.
7. Make sure you include the name of the author and article and use “author tags” (see list below) to let the reader know you are talking about what the author said and not your own ideas.
8. Re-read your piece. Does it flow well? Are there too many details? Not enough? Your summary should be as short and concise as possible.

Sample Format

Author Tag: You need to start your summary by telling the name of the article and the author. Here are three examples of how to do that (pay close attention to the punctuation):

1. *In “How the Civil War Began,” historian John Jones explains...*
2. *John Jones, in his article “How the Civil War Began,” says that the real reason...*
3. *“How the Civil War Began,” by historian John Jones, describes....*

First Sentence: Along with including the article's title and author's name, the first sentence should be the main point of the article. It should answer the question: What is this essay about? (thesis).

Example:

In “How the Civil War Began” by John Jones, the author argues that the real reason for the start of the Civil War was not slavery, as many believe, but was instead the clash of cultures and greed for cash.

Rest of Summary: The rest of your essay is going to give the reasons and evidence for that main statement. In other words, what is the main point the writer is trying to make and what are the supporting ideas he or she uses to prove it? Does the author bring up any opposing ideas, and if so, what does he or she do to refute them?

Here is a sample sort of sentence:
___________ *is the issue addressed in "(article's title)" by (author's name). The thesis of this essay is* ___________ *. The author's main claim is* ___________ *and his/her sub claim is* ___________ *. The author argues* ___________ *. Other people argue* ___________ *. The author refutes these ideas by saying* ___________ *. His/her conclusion is* ___________ *.*

Author Tag List

Author's Name	**Article**	**Words for "Said"**	**Adverbs to Use With "Said"**
James Garcia	"whole title"	argues	carefully
Garcia	"first couple of words"	explains	clearly
the author	the article (book etc.)	describes	insightfully
the writer	Garcia's article	elucidates	respectfully
the historian (or other profession)	the essay	complains	stingingly
essayist	the report	contends	shrewdly

Transition Words List

Contrast	**Adding Ideas**	**Emphasis**
Although	In addition	Especially
However	Furthermore	Usually
In contrast	Moreover	For the most part
Nevertheless	In fact	Most importantly
On the contrary	Consequently	Unquestionably
Still	Again	Obviously

Response

Response answers: What do you think? Does this article persuade you?

How to Write

Generally, your response will be the end of your essay, but you may include your response throughout the paper as you select what to summarize and analyze. Your response will also be evident to the reader by the tone that you use and the words you select to talk about the article and writer. However, your response in the conclusion will be more direct and specific. It will use the information you have already provided in your summary and analysis to explain how you feel about this article. Most of the time, your response will fall into one of the following categories:

- You will agree with the author and back your agreement up with logic or personal experience.
- You will disagree with the author because of your experience or knowledge (although you may have sympathy with the author's position).
- You will agree with part of the author's points and disagree with others.
- You will agree or disagree with the author but feel that there is a more important or different point which needs to be discussed in addition to what is in the article.

How will this article fit into your own paper? How will you be able to use it?

Here are some questions you can answer to help you think about your response:

1. What is your personal reaction to the essay?
2. What common ground do you have with the author? How are your experiences the same or different from the author's and how has your experience influenced your view?
3. What in the essay is new to you? Do you know of any information the article left out that is relevant to the topic?
4. What in this essay made you re-think your own view?
5. What does this essay make you think about? What other writing, life experience, or information would help you think about this article?
6. What do you like or dislike about the essay and/or the ideas in the essay?
7. How much of your response is related to your personal experience? How much is related to your own worldview? How is this feeling related to the information you know?
8. How will this information be useful for you in writing your own essay? What position does this essay support? Or where might you use this article in your essay?

Sample Format

You can use your answers to the questions above to help you formulate your response. Here is a sample of how you can put this together into your own essay:
Before reading this article, my understanding of this topic was ___________. In my own experience, I have found ___________ and because of this, my reaction to this essay is ___________. Interestingly, I have ___________ as common ground with the author/audience. What was new to me is ___________. This essay makes me think ___________. I like/dislike ___________ in the essay. I will use this article in my research essay for ___________.

Vocabulary

- article – статья;
- summary – краткое изложение, конспект;
- rendering – реферирование;
- uncommon – редкий;
- finding – находка, открытие, полученные данные;
- to pay attention – уделять/обращать внимание;

- conclusion – умозаключение, вывод;
- to highlight – выделять;
- to comprehend – понимать, осмысливать;
- rough draft – эскиз, набросок;
- firm grasp – четкое понимание;
- assignment – предписание, инструкция, задание;
- to explain – объяснять;
- in plain language – простым языком;
- referring to – ссылаясь на;
- meaning – значение, смысл;
- to convey – выражать, передавать (идею, смысл);
- appropriate – подходящий, соответствующий;
- to feature in – принимать участие;
- concisely – кратко, сжато, лаконично, выразительно;
- cut and paste – «вырезать и вставлять» (объемно цитировать без ссылки на источник, компилировать);
- jumble – куча; беспорядочно сваленные в кучу вещи;
- borders on – граничить grade – оценка, отметка;
- option – вариант, альтернатива; опция.

Task 2. Read and translate the text. Use its main ideas for rendering scientific articles.

How to write a Summary of a scientific article

Summarizing or rendering of a scientific article demonstrates your understanding of the material and presents this information to an audience that may not have a science background. It is not uncommon for a scientific article to describe an experiment and discuss its findings. To write an effective summary, you must be able to focus on the main ideas of the article. This also helps to understand scientific research better.

Instructions:

1. Read the entire article. Pay attention to the experiment methods and the conclusions presented. Read the article more than once, if necessary.
2. Look up any words or methods you do not understand.
3. Go through the article, and highlight its main ideas. Make sure you understand the main points in each para graph. Take notes so you have a starting point for your summary.
4. Test your understanding of the artic le by asking yourself questions about it. Try explaining the concept of the article to a friend or family member in non-scientific language. Determine if you can clearly explain the article in a way that is easy to comprehend.
5. Start a rough draft of your summary, using the notes you've written. Review the article to ensure you have a firm grasp of the conclusion. Summarize the article's conclusion. Offer your own interpretation of the conclusion along with your opinion of the article's content.

Task 3. Look through the “George Mason University Recommendations” on the writing of a summary of a scientific article. Be ready to answer the questions.

This assignment is generally intended to help you learn to synthesize scientific materials and communicate the main points effectively, using plain language.

Start by making sure you understand the central points of what you read. Explain the article in plain language to someone else and answer questions without referring back to the article, to make sure you have grasped the essence of what you read. Dr. James Lawrey in the Biology Department uses this assignment to teach students to pick out the meaning of an article and convey the main points. The appropriate writing style for a summary of a scientific article is to use simple sentences that express one or two ideas. An example might be a story featured in the mainstream media that explains a recent scientific finding, bringing out the important aspects concisely and without too much scientific jargon. Do not “cut and paste” from the article. When students do not really understand what they read, their writing is a jumble of statements nearly straight from the article, with no interpretation or synthesis of the article's findings. This strategy is common among students who wait until the last minute to complete assignments. Besides the fact that this practice borders on or actually is plagiarism, it shows that students do not understand what they are writing about, and their grades reflect this.

Task 4. Answer the questions.

1. Who is James Lawrey? 2. What should you do at first while writing a summary? 3. Does the author limit the number of times his students should read the scientific article they are to summarize? 4. When do students use “cut and paste” function while writing a summary? 5. How do you understand the term “plagiarism”?

Task 5. Retell the Instructions on writing a Summary of a scientific article.

Task 6. Read the definition of summarizing/rendering in Russian. Try to remember as many set phrases as possible. Use them in the rendering of scientific articles.

Реферирование научных статей на английском языке – важный навык, необходимый любому современному инженеру. Суть реферирования можно свести к анализу прочитанной англоязычной работы с выделением ее главной идеи, описанием перечисленных автором фактов и доводов и подведением итогов. С этой целью можно использовать ряд вводных языковых конструкций.

1. Название статьи, автор, стиль. The article I’m going to give a review of is taken from… – Статья, которую я сейчас хочу проанализировать из… The headline of the article is – Заголовок статьи… The author of the article is… – Автор статьи… It is written by – Она написана (кем)… The headline foreshadows… – Заголовок приоткрывает…

2. Тема. Логические части. The topic of the article is… – Тема статьи это… The key issue of the article is… – Ключевым вопросом в статье является… The article under discussion is devoted to the problem… – Обсуждаемая статья посвящена проблеме… The author in the article touches upon the problem of… – В статье автор затрагивает проблему…. I'd like to make some remarks concerning… – Я бы хотел(а) сделать несколько замечаний по поводу… I'd like to mention briefly that… – Хотелось бы кратко отметить, что… I'd like to comment on the problem of… – Я бы хотел(а) прокомментировать проблему… The article under discussion may be divided into several logically connected parts which are… – Статья может быть разделена на несколько логически взаимосвязанных частей, таких как…

3. Краткое содержание. At the beginning of the article its author… – В начале статьи автор… …describes – описывает …depicts – изображает …touches upon – затрагивает …explains – объясняет …introduces – знакомит …mentions – упоминает …makes a few critical remarks on – делает несколько критических замечаний о The article begins (opens) with a (the)… – Статья начинается… …description of – описанием …statement – заявлением …introduction of – представлением …the mention of – упоминанием …the analysis of / a summary of – кратким анализом …the characterization of – характеристикой …(author's) opinion of – мнением автора …the enumeration of – перечнем In conclusion the author – в заключение автор …dwells on – останавливается на …points out – указывает на то …generalizes – обобщает …reveals – показывает …exposes – показывает …accuses / blames – обвиняет …gives a summary of – дает обзор…

4. Отношение автора к отдельным моментам. The author gives full coverage to… – Автор полностью охватывает… The author outlines… – Автор описывает… The article contains the following facts…/ describes in details… – Статья содержит следующие факты …. / подробно описывает… The author starts with the statement of the problem and then logically passes over to its possible solutions. – Автор начинает с постановки задачи, а затем логически переходит к ее возможным решениям. The author asserts that… – Автор утверждает, что … The author resorts to … to underline… – Автор прибегает к …, чтобы подчеркнуть… Let me give an example… – Позвольте мне привести пример…

5. Вывод автора. In conclusion the author says / makes it clear that…/ gives a warning that… – В заключение автор говорит / проясняет, что… / предупреждает, что… At the end of the article author sums it all up by saying … – В конце статьи автор подводит итог всего этого, говоря… The author concludes by saying that… /

draws a conclusion that… / comes to the conclusion that… – В заключение автор говорит, что... / делает вывод, что… / приходит к выводу, что…

6. Выразительные средства, используемые в статье. To emphasize … the author uses… – Чтобы акцентировать внимание … автор использует… To underline … the author uses… – Чтобы подчеркнуть … автор использует To stress… – Чтобы усилить / подчеркнуть… Balancing… – Балансируя…

7. Ваш вывод. Taking into consideration the fact that – Принимая во внимание тот факт, что The message of the article is that… /The main idea of the article is… – Основная идея статьи (послание автора)… In addition… / Furthermore… – Кроме того… On the one hand…, but on the other hand… – С одной стороны …, но с другой стороны… Back to our main topic… – Возвращаясь к нашей основной теме… To come back to what I was saying… – Чтобы вернуться к тому, что я говорил(а)… In conclusion I'd like to… – В заключение я хотел(а) бы… From my point of view… – С моей точки зрения… As far as I am able to judge… – Насколько я могу судить… My own attitude to this article is… – Мое личное отношение к этой статье... I fully agree with… / I don't agree with… – Я полностью согласен / не согласен с… It is hard to predict the course of events in future, but there is some evidence of the improvement of this situation. – Трудно предсказать ход событий в будущем, но есть некоторые свидетельства улучшения ситуации. I have found the article dull / important / interesting /of great value – Я нахожу статью скучной / важной / интересной/ имеющей большое значение (ценность).

Task 7. Retelling

Read text of the article several times. Work in pairs or groups. Divide text into parts, so that each group will have at least several sentences. Select the key words in the texts, type them in Word it Out (https://worditout.com/) and generate a cloud. Retell the story with the help of the generated word clouds. If two words need to be together, imagine "suffer from", you only need to insert _ between the two words and they'll be kept together in the cloud.

Пример рассказа о научных интересах магистранта:

1. What is your name? – My name is Ivan Ivanovich Ivanov.
2. What educational institution did you graduate from? When? – I graduated from …in 20…
3. What is your speciality? – My speciality is …/ My profession is …

4. Why did you decide to take a post-graduate course? – I decided to take a post graduate-course because I had been interested in science since my 3-d year at the University / because scientific approach is very important in my profession.

5. What is the subject of your future scientific research? – The subject of my scientific research is … – My future scientific research is devoted to the problem of … – My future scientific research deals with the problem of …

6. Who is your scientific supervisor? – My scientific supervisor is Ivan Petrovich Petrov, Professor, Doctor of technical/ economic sciences, Head of the Chair of … / Head of the Department of … – He has got a lot of publications devoted to the problem of …

7. Have you ever participated in any scientific conferences? – Yes, I've participated in many conferences devoted to the most actual problems of economy/physics/geodesy/hydrology etc. – Not yet, but I hope, together with my supervisor, I'll prepare some reports for scientific conferences / I'll take part in several conferences in the near future.

8. Do you have any publications? – Yes, I've got some publications connected with my research. – Not yet, but I hope, together with my supervisor, I'll prepare some publications, they will be devoted to my research.

9. What methods are you going to use in your investigation? – Together with my supervisor we are going to apply such methods as theoretical, experimental, practical and computational methods because they will help me to complete my research.

10. What will your scientific research give the world? In what way can your investigation/research be useful to … science?

– I think / I hope / I dare say that the problem of our scientific research is very urgent and our scientific research will be very useful for … / it will help people in the field of …

СПИСОК СОКРАЩЕНИЙ

сокращение	**читается/означает**	**перевод**
%	percent (per cent) [pə'sent]	процент
° C	degrees Centigrade	градус (Цельсия)
° F	degrees Fahrenheit	градус (Фаренгейта)
etc.	[et'set(ə)rə]	и так далее
e. g.	for example	например
i. e.	that is	то есть

Температура читается:

25° C – twenty-five degrees Centigrade ['sentıgreıd] (по шкале Цельсия);
34° F – thirty-four degrees Fahrenheit ['færənhaıt] (по шкале Фаренгейта).

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Кириллова, В. В., Вихман, Т. М. Английский язык [Текст]: учеб.-метод. пособие по переводу научно-технической литературы для студентов и аспирантов технических специальностей / В. В. Кириллова, Т. М. Вихман; М-во образования и науки РФ, СПбГТУРП. – СПб.: СПбГТУРП, 2010. – 154 с. [Электронный ресурс]. – URL: http://www.nizrp.narod.ru/english-kirilova.htm
2. Барочкин, Е. В., Зорин, М. Ю., Барочкин, А. Е. Общая энергетика [Текст]: учебное пособие / Е. В. Барочкин, М. Ю. Зорин, А. Е. Барочкин // Цифровой образовательный ресурс IPR SMART. [Электронный ресурс] – URL: https://www.iprbookshop.ru/114940.html – Режим доступа: для авторизир. пользователей. – 3-е изд. – Москва, Вологда : Инфра-Инженерия, 2021. – 316 с.
3. Электронный словарь. [Электронный ресурс]. – URL: www.multitran.ru
4. Стронг, А. В. Стронг, А. В. Новейший англо-русский, русско-английский словарь с транскрипцией в обеих частях [Текст] / А. В. Стронг // Цифровой образовательный ресурс IPR SMART. [Электронный ресурс]. – URL: https://www.iprbookshop.ru/44107.html – Режим доступа: для авторизир. пользователей. – Москва : Аделант, 2015. – 800 с.
5. Кириллова, В. В., Лиоренцевич, Т. В., Шапрапа, Т. С. Английский язык. Некоторые трудности перевода с английского языка на русский литературы по специальности «Промышленная теплоэнергетика» [Текст]: учеб.-метод. пособие / В. В. Кириллова, Т. В., Лиоренцевич, Т. С. Шапрапа ; М-во образования и науки РФ, СПбГТУРП. – СПб. : СПбГТУРП, 2015. – 75 с. [Электронный ресурс]. – URL: http://nizrp.narod.ru/metod/kafinyaz/9.pdf
6. Мюллер, В. К. Новый англо-русский, русско-английский словарь [Текст] / В. К. Мюллер // Цифровой образовательный ресурс IPR SMART. [Электронный ресурс]. – URL: https://www.iprbookshop.ru/44108.html – Режим доступа: для авторизир. пользователей. – Москва : Аделант, 2014. – 512 с.

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