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Article

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An Investigation into the Effect of Decorative Covers on the Heat Output from LPHW Radiators

Laurence Brady, Mawada Abdellatif, Jeff Cullen, James Maddocks, Ahmed Al-Shamma'a

Abstract

Low pressure hot water radiators are the most popular type of heat emitter used in UK buildings. Because of high surface temperatures, or for aesthetic reasons, radiators are often encased in some form of architectural casing which reduces their output. An alternative method of reducing surface touch temperature and enhancing the appearance of radiators may be achieved by using decorative covers. This research examines how the heat output from a radiator is affected by the application of an innovative magnetic decorative cover to the radiator surface. A series of tests was run which compared the heat output from a bare radiator, to the output when the radiator is installed (a) under a magnetic cover, and (b) within a traditional wooden cover. Since the heat output from a radiator is by convection and radiation, thermocouples were located on radiator and supporting wall surfaces, as well as in the air spaces around the radiator. By this means the temperature differences which drive both heat transfer mechanisms could be determined. Additionally, temperatures were also monitored by a thermal imaging camera. The scenario tests were carried out under steady state conditions at closed room space, with controlled room temperature. Results from the tests showed that magnetically applied radiator covers efficiency increased by 13 - 20% relative to traditional radiator wooden cover. In terms of space-heating, this can reduce energy input needed to achieve comfort temperature. This demonstrates that magnetic radiator covers can offer improved heating system energy performance.

Keywords: *Convection, radiator, radiation, radwraps, heat transfer, wooden cover*

1. Introduction

Domestic energy consumption is significant and, in fact accounts for over 30% of the UK national energy demand. The domestic sector is the second largest UK energy user after transport (Bangert, 2010). Therefore in the context of UK national greenhouse gas emission targets, improved energy efficiency in residential properties can make an important contribution (DECC, 2012), and is therefore a key area for research.

Building regulations for new build housing are driving part of this strategy however the challenge of reducing the energy used by the existing housing stock must be tackled. In the short to medium term, upgrading of the existing aging residential infrastructure will be necessary. More energy efficient homes will help to offset emissions as aging properties are gradually replaced.

Generally space heating systems in buildings are radiator and floor heating or their combinations and accounts for an increasingly large proportion of the energy consumption of the building sector (Tu et al., 1996). For example the most important energy end-use in the building sector in the UK is space heating, which accounts for over 60% of delivered energy and over 40% of energy costs (Herring et al., 1998). A study in 1980s indicated that over two-thirds of the energy savings achievable in buildings would come from space heating (Herring et al., 1998). Since the energy crisis in 1970s, enormous efforts have been made to promote the energy efficiency of heating systems in buildings (EIA, 1999; Jonathan and Jiang, 1994). However, energy efficiency is still below expectation. Research conducted in the UK predicted a potential for energy saving of up to 70% in heating (Herring et al., 1998). According to Energy Commissioner of EU, a saving potential of around 22% of present consumption in buildings can be realised by 2010 (Warren, 2002).

There are a range of radiator types available but in each case the heat emitting process is the same (Beck, 2015). Distribution and emission losses of the radiator have not been widely studied. The study by Saute, (1985) reports tabulated values for distribution and emission losses of 15% for heating curves 55/45^{0}C and 19% for 70/55 ^{0}C in residential dwelling radiator heating system. A study by Olesen et al. (2011) reports additional emission loss up to 5% of the heat emission of radiator in old buildings with poor insulation and less than 1% in new buildings with good insulation. General movement towards low-energy, this has created new challenge for heating systems. Heating need obviously decrease the control and system losses are stressed compared to existing buildings with higher heating energy need (Maivel and Kurnitski, 2013).

Investigations using CFD analysis of natural and forced convection for radiators and vertical plates have featured in several studies (Embaye (2015), Myhren and Holmberg, (2008); Holmberg and Myhren (2004); Holmberg (1984)). Outputs from these researches have been aimed at increasing radiator thermal efficiency. For example, increasing the heat transfer surface by convection fins improves heat emission, although these kinds of additions can also increase production costs. Less costly methods of boosting heat outputs have included directing ventilation air towards heated radiator surfaces, or forcing air between radiator panels.

Radiator surfaces can be hot to the touch. For safety or aesthetic reasons radiators are often located inside decorative casings. Typically these casings are made of timber with a fascia grille. A less expensive decorative effect is to mount the radiator beneath a shelf. Both of these arrangements will affect the heat transfer from the radiator to the heated space. Many studies have examined the thermal efficiency of radiators in terms of radiator heat emission compared to heat energy input. An alternative view of efficiency considers the process the effectiveness of radiators in heating the occupied space.

Some radiator manufacturers use stoneware panels to cover their radiators, basically for aesthetic reasons. They claim that the panels also improve the thermal energy properties of these radiators (Menendez-Diaz., et al., 2014). The attachment of a stoneware panel to the heat emitter surface has thus been proposed as a thermal energy accumulator and radiator (Llana, 2000). The logic supporting this arrangement is that once the radiator is heated to working temperature, the stoneware panel maintains this temperature and therefore the emitter radiates heat for a longer time after the heater has switched off. Guidance from the Chartered Institute of Building Services Engineers (CIBSE Guide B, 2005) indicates that encasing radiators reduces heat output by 20% or more, and a radiator shelf could reduce heat output by 10%.

Meeting the requirements to enhance the appearance of a radiator whilst reducing surface touch temperature can also be achieved by applying a magnetically attached cover to the radiator surface. This paper introduces this innovative magnetic cover, called radwraps, in order to minimise the heat loss that occurs when using traditional wooden casing. It also assesses how the new material affects the heat transfer to the occupied space and compares this with a traditional cover or a radiator shelf, as no study considered this before apart from the CIBSE, which considered the traditional cover. Results from this study confirm the findings of the CIBSE that there is a significant reduction in heat output, reached up to 40%, when using the timer casing, however when replaced with the new magnetic cover the reduction in heat out dropped to 11% only. Additionally, the magnetic cover has the advantage of having lower cost compared to the wooden cover, which encourages users to install it.

2. Radwraps Magnetic Material

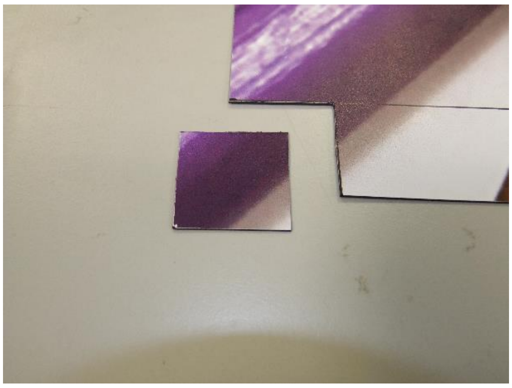
Radwraps cover is rubber magnet with 85%-95% Strontium Ferrite and 5-15%Chlorinated Polyethylene and has specific gravity or bulk density 3.6 – 3.8 g/cc. The product is stable has no physical hazard and environmental effects. It is necessary to ensure that contact with strong mineral acids and oxidizing agents is avoided. The product may be disposed in an approved landfill or recycled (Material safety data sheet).

Impact of radwraps exposure to varying temperatures and time duration has been explored in this study. A sample coupon of 3cm by 3cm from radwraps was loaded into an oven and temperature set to 105°C (Figure 1-a, b). After 1 hour sample has relaxed to shape of test crucible with no thermal damage (Figure 1-c). After 24 hrs@ 105°C (Figure 1-d), sample has taken the shape of the crucible, and retained that.

- Sample is still flexible.
- Shape could be restored by flattening before sample cools down.

Then temperature was increased to 150°C and after 24 hrs it is found that ((Figure 1-e, f),

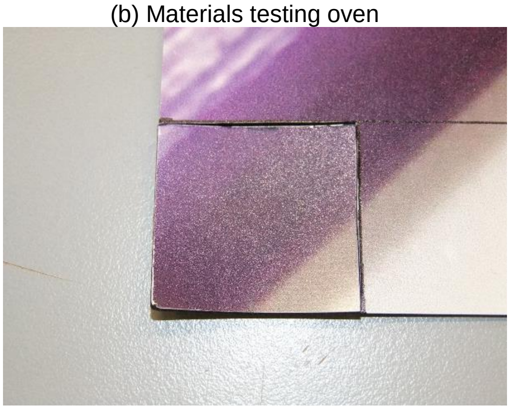
- Sample has changed –discoloured and hardened
- Sample is brittle
- Sample has not combusted



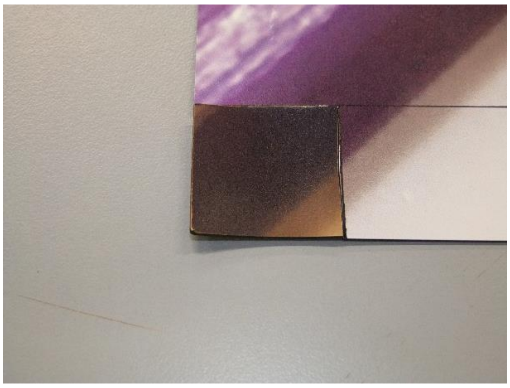
(a) Sample coupon of radwraps

(b) Materials testing oven

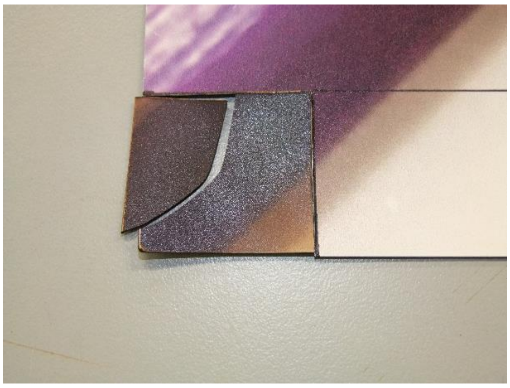
(c) Sample after I hour at 105°C



(d) Sample after 24 hours at 105°C



(e) Sample after 24 hour at 150°C



(f) Effect of trying to flex sample after 24 hour at 150°C exposure

Figure 1 Material testing of radwraps at high and low temperature

3. Methodology

To perform the experiment of the radiator cover for purpose of assessment of heat output, a miniature domestic central heating system has been built (See Figure 2 and appendix). This system comprises a single double panel radiator in which hot water is circulated. Thermocouple temperature measurements were recorded over the test period. Temperatures were also recorded using a thermographic camera. These measuring equipments in the appendix have the following specification:

- Thermocouples: Type K and measures temperature between -35°and +220°C.

- Thermocouple Data Logger (TC-08): used to record temperature between 0-50^{0}C on computer with the thermocouples plugged to it. TC-08 works with PicoLog data acquisition software that can collect up to 1 million samples. Temperature accuracy Sum of ±0.2% of reading and ±0.5 °C.
- Thermoanemometer: is Digi-Sense Hot Wire with NIST Traceable Calibration. It measures air velocities up to 25 m/s with accuracy ± (5% + 1 digit) reading or ± (1% + 1 digit) full scale. It measures the temperature in range of 32 to 122°F (0 to 50°C) with accuracy of ±1.8°F (±1°C).
- Single-Jet Hot Water Meter: measure flow rate with maximal temperature cold water 30 °C and maximal temperature warm water 90 °C. Calibration error tolerance for warm water of Qmax ± 3 % and Qmin ± 5 %.

Before the tests were carried out the system was operated for some hours to reach steady state conditions. Four scenarios were considered:

- Bare radiator
- Radiator with radwraps cover applied
- Radiator with radwraps cover applied and radiator shelf located above radiator
- Radiator with tradition architectural (timber) cover

Each simulation was carried out for 20000 seconds during which temperature readings were recorded every 15 seconds. Surrounding conditions were the same for each test with external ambient air temperature of 20^{0}C. Water flow rate to the radiator was constant for all scenarios($8.33 * 10^{-5}\, m^3.s^{-1}$).

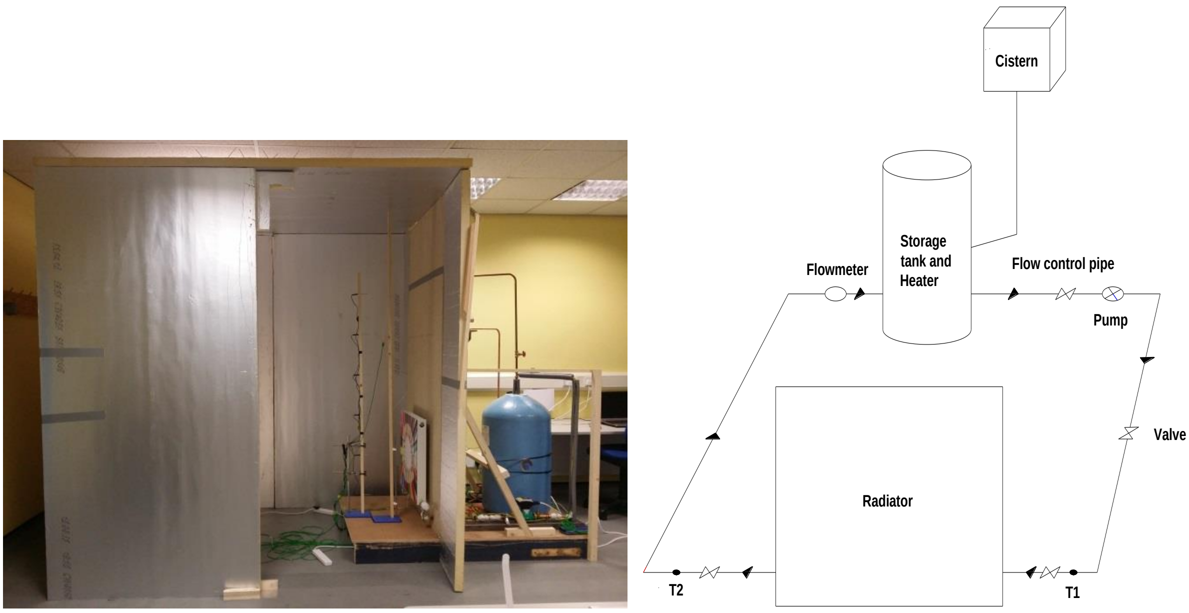
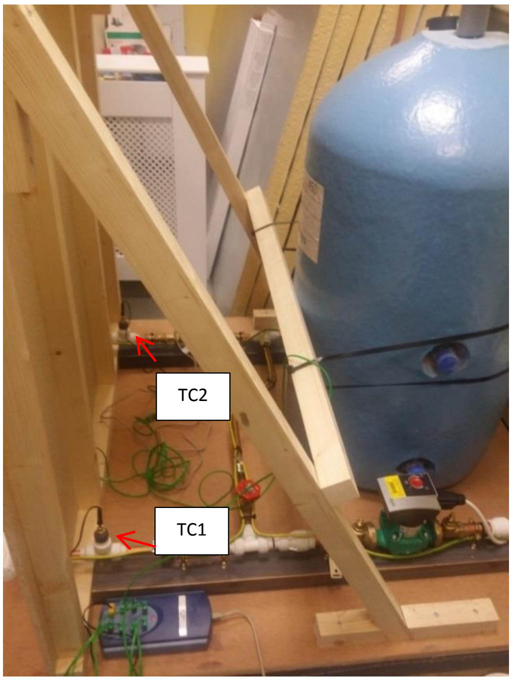
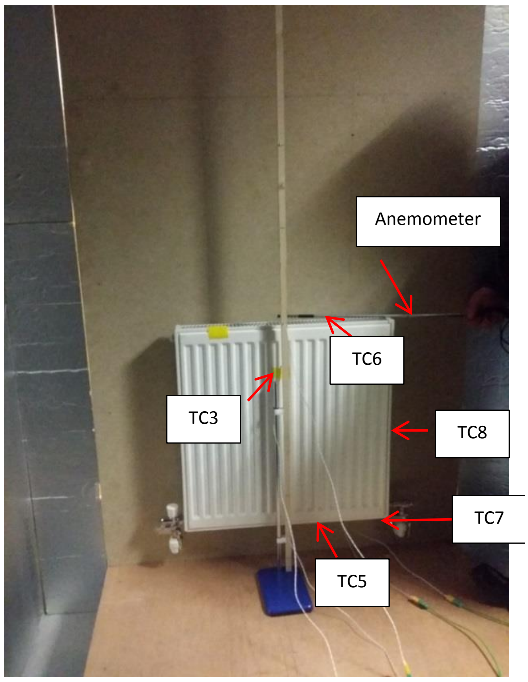


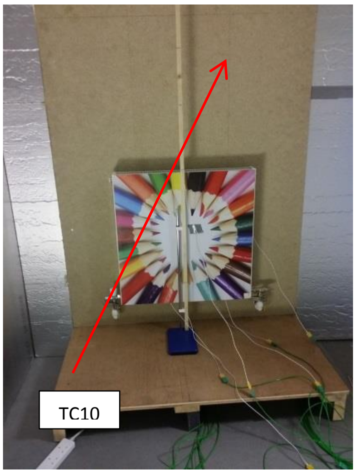
Figure 2: Schematic of apparatus and general set up of radwraps experiment



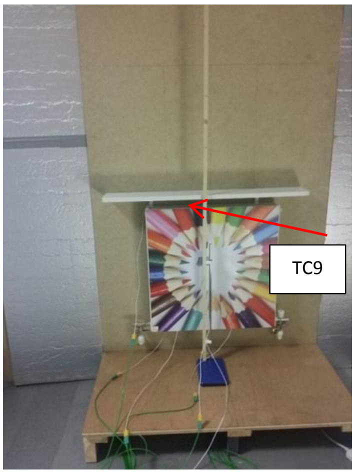


(a) Test setting at back of radiator system

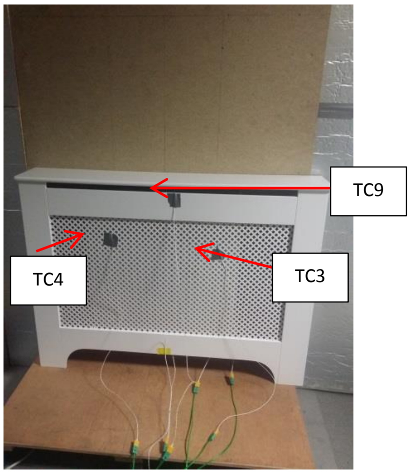
(b) Bare radiator



(c) Radwraps cover



(d) Radwraps cover/shelf



(e) wooden cover

Figure 3: Location of thermocouples for the four scenarios of the experiment

Table 1 Name of different thermocouples used for the experiment

Thermocouple	Name
TC1	Water inlet temp
TC2	Water outlet temp
TC3	surface temp of radiator, rad wraps or wooden cover (solid part)
TC4	surface temp of wooden cover (voids)
TC5	air temp below radiator for bare radiator, radwraps, radwraps with shelf or wooden
TC6	air temp above radiator for bare radiator/ radwrap scenarios
TC7	temp of back of radiator for bare radiator/ radwraps/ radwraps with shelf scenarios
TC8	temp of wall for radiator/radwraps/ radwraps with shelf scenarios
TC9	air temp at top front of the radwraps with shelf /wooden cover scenarios
TC10	Room temp

3.1 Convection and Radiation Emission from a Radiator

The process of providing heat output from the radiator is achieved by circulated hot water through the radiator raising its surface temperature above space ambient. The temperature difference between the radiator and the surrounding air creates a driving force which generates heat transfer from the warm heat emitter to the room. The heat emission (Φ Watts) from radiators, (manufactured to BS EN 442-2-2014) to a space may be determined from the following formula-

$$\Phi = K_m . \Delta T^n \qquad (1)$$

Where

K_m is the constant of the model and *n* is the exponent of the characteristic equation

Heat emitted from radiator through two main process, convection and radiation. Given the frequency of temperature recordings, it was considered that steady state heat transfer equations for convection and radiation would give a valid comparison with acceptable error limitations.
Despite their name radiators much of the heat delivered to the space is by natural convection (Aydar and Ekmekci, 2012). The definition provided by Oughton and Wilson (2015) illustrates the role of convection for radiators: “Convection is a process in which heat transfer involves the movement of a fluid medium to convey energy, the particles in the fluid having acquired heat by conduction from a hot surface. An illustration commonly used is that of an ordinary (so-called) radiator which warms the air immediately in contact with it: this expands as it is heated, becomes lighter than the rest of the air in the room and rises to form an upward current from the radiator”.

3.1.1 Heat Emission by Convection

<u>Bare radiator, Radwraps and Radwraps with shelf</u>

The heat emission from a wall-mounted double panel radiator by convection mainly comprises the output from the room-facing surface, the output from the wall-facing surface, and the heat in the air which flows between the two panels (Figure 4).Output from room and wall facing surfaces for the three conditions of bare radiator, Radwraps and Radwraps with shelf may be found from (Long and Sayma, 2009):

$$Q_{C1} = h\,A\,(T_s - T_{room}) \qquad (2)$$

Where,

Q_{C1} Is the convective heat output (Watts)

A is surface area of radiator ($0.36 m^2$)

h is convection coefficient ($W/m^2.^0C$)

T_s is front surface temperature (TC3 ^0C, TC7 ^0C) for radiator or radwraps

T_{room} is room temperature (TC8 ^0C, TC10 ^0C)

Since the fluid properties do not vary greatly and the temperature range is limited, the convective coefficient (h) for a vertical surface is determined from (Simonson, 1988):

$h = 1.31\ (\theta)^{0.33}$ Turbulent flow (3)

$h = 1.41\ (\frac{\theta}{l})^{0.25}$ Laminar flow (4)

The fluid flow characteristic (turbulent or laminar) may be found from determining the numerical value of the product of two dimensionless numbers (Grashoff and Prandtl) as follows:

$Laminar\ flow\ \ 10^4 < G_r P_r < 10^9$ or $Turbulent\ flow\ \ 10^9 < G_r P_r < 10^{12}$ (5)

The Prandtl number may be found from direct empirical expression in the case of air (Dixon, 2007):

$Pr = 0.680 + 4.69 * 10^7 * (T_K + 540)^2$ (6)

$T_K = 273 + \frac{1}{2}(surface\ temp\ + room\ tempt)$ (7)

$Gr = \frac{\beta\ g\ l^3\ \theta}{v^2}$ (8)

Where

$\beta = coefficient\ of\ cubical\ expansion\ of\ the\ fluid\ \left(\frac{1}{303}\right)$

$g = acceleration\ due\ to\ gravity\ (9.81\ m.s^{-2})$

$l = characteristic\ dimension\ (radiator\ height = 0.60m)$

$\theta = temperature\ difference\ between\ radiator\ surface\ and\ room\ air$

$v = kinematic\ viscosity\ (\ 1.57 * 10^{-5}\ m^2.s^{-1})$

Also there is a heat output by convection from the narrow air flow passages between the double panels which effectively create “duct” through which the buoyant heated air flows (Figure 4). The output from these two components can be determined from:

$Q_{c2} = V_{air} * CSA * \rho * C_p * \Delta t$ (9)

Where,

Q_{C2} is the convective heat output (KWatt)

V_{air}=Air Velocity above the radiator, or top front of radwraps with shelf

CSA = the cross sectional area of fluid flow

ρ = density of air (1.2 kg/m^3)

C_p= the air specific heat capacity (1.01 kJ/Kg.^{0}C)

Δt = temperature difference of air leaving and entering the radiator (^{0}C) (TC6 –TC5) for the case of radiator or radwraps and (TC9 –TC5) for radwraps with shelf

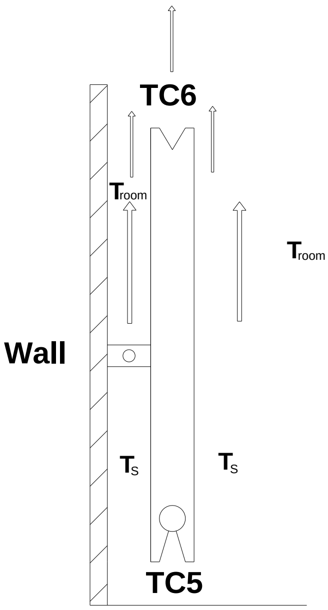


Figure 4: Convective heat for bare radiator and radwraps

Wooden cover, the convective heat output would mainly be from front side of the radiator cover A_1 (Figure 5), which can be estimated from equation 2 with following conditions:

A is area of cover (A_1=0.41m^2)
T_{room} is room temperature (TC10)
T_s is cover surface temperature (average TC3 andTC4)

There may also be some convective current on the outside of the casing A_2 (Figure 5). This can be determined from equation 8 with temperature difference (TC9 –TC5).

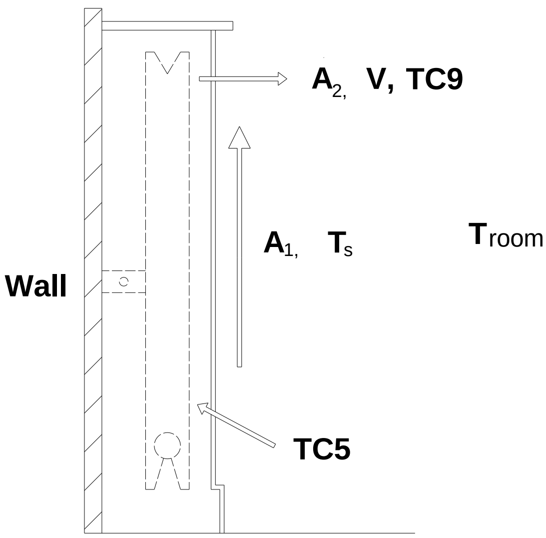


Figure 5: Convective heat in front of the wooden cover

3.1.2 Radiation:

Bare radiator, Radwraps and Radwraps/shelf

There is radiation heat output from the radiator to the room which can be determined as follows (Long and Sayma, 2009),

$$Q = A * \epsilon * \sigma (T_s^4 - T_{room}^4) \quad (10)$$

Where,

ϵ=0.90

σ=5.6703*10^{-8} W/m^2.k4

A = 0.36m^2

T_s =*TC3*

T_{room} =*TC10*

Also there is radiation heat output to back wall:

$$Q = A * F_{1-2} * \sigma (T_s^4 - T_{wall}^4) \quad (11)$$

Where,

T_{wall} =TC8

T_s =TC7

$$F_{1-2} = \frac{1}{\frac{1}{\epsilon_1}+\frac{1}{\epsilon_2}-1} = 0.826$$

ϵ_1=0.90

ϵ_2=0.91

A = 0.36m^2

Wooden cover

There is a radiation heat output from the front side of radiator cover only to the room which can be determined from equation (10).

There is also some heat lost through the wall by conduction under the four scenarios which can be determined by applying Fourier's law of heat (Long and Sayma, 2009),

$$Q_T = -KA\frac{T_2 - T_1}{L} \quad (12)$$

Where,

K = Thermal conductivity of the chipboard wall = 0.2 W/m.K

A = Surface area of the wall corresponding to the radiator 0.36 m^2

L = Chipboard wall width 0.18m

$T_{1,}$ $_{T2}$ = Temperature of the two sides of the wall (20^{0}C, TC8)

4. Comparison of Decorative Covers-Test Results

The graphs of Figure 6 show the temperature patterns on the surfaces of the radiator and covers. All convection coefficients for the radiator and different covers were obtained from equation 4 base on the Grashoff and Prandtl number as the air flow was found to be laminar. Values of this coefficient at the back of the radiator are higher than these at the front face, for all considered scenarios, due to the limited space between the back of the radiator and the wall (Table 3). The front face of the radiator has a large space which causes the room temperature to be lower than the temperature at the back of the radiator. Moreover the value of convection coefficient for radwraps with shelf, has higher value compared to other covers, while the least coefficient value is associated with the wooden cover.

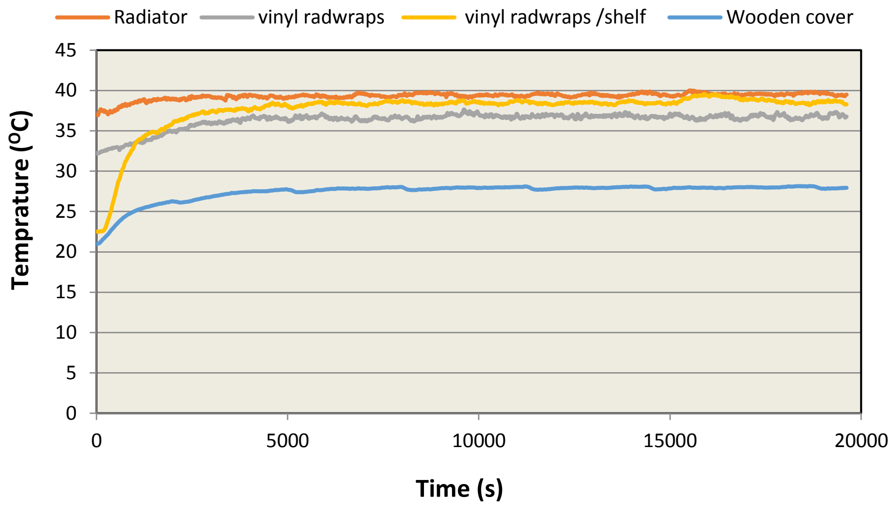


Figure 6: temperature pattern on surface of radiator/covers for each scenario

Table 2: Air flow characteristics measured during the experiment for estimation of heat output

Scenario	Air Velocity (m^2/s)	Air flow CSA (m^2)
Above bare radiator	0.58	0.0285
Above radwraps	0.46	0.0285
Top front of radwraps/shelf	0.57	0.0245
Top front of wooden cover	0.54	0.0196

Table 3: Typical values of the convection coefficient in front and back of the radiator/cover scenarios during the steady state condition

Scenario	G_r*P_r	Air Flow Classification	Convection coefficient ($W/m^2.{}^0C$)
Bare radiator	(0.152251774 - 0.233467304)*10^9	Laminar	2.80 (front) ; 2.96 (back)
Radwraps/shelf	(0.074677955 - 0.160074421)*10^9	Laminar	2.65 (front); 2.95 (back)
Radwraps	(0.137308406 - 0.253723545)*10^9	Laminar	2.43 (front); 2.93 (back)
Wooden cover	0.029931831*10^9	Laminar	1.63 (front only)

The total heat transferred in each of the radiator scenario has been determined (equations 2-11) and using temperature, air flow measurements and convection heat coefficient in Table 2, 3. It can be seen that the radwraps cover with shelf provided the highest heat output (314.85Watts). The next highest output was obtained from radiator plus radwraps cover (267.67Watts). The radiator plus traditional wooden gave a lower output (190.43Watts) (Figure 7-a). This result from these tests validates the estimate that a shelf surface over the radiator with radwraps can aid convection and produce the least restriction to emitter heat output. Maximum, minimum and mean values of heat transfer in each scenario also confirm the results obtained above, although it has been assessed for the whole test duration and not only at the steady state condition (Figure 8). Furthermore some of this heat energy is absorbed by the wall upon which the radiator is mounted. Although internal room heat will eventually transfer to colder outside air, it is important that this energy plays a part in space heating before contributing to room heat loss. Figure 7-b showed that heat losses directly to outside walls were greater under a wooden cover scenario. The vinyl radwraps /shelf combination demonstrated that the amount of direct heat loss to outside wall showed no increase from the bare radiator arrangement.

The main reason for reduction of wooden cover performance is due to reduced convection in front of the cover surface. This is caused by the lower casing surface temperature. Most of positive heat transfer to the air from this cover caused by convection outside the casing (upper side-see Figure 3-e).

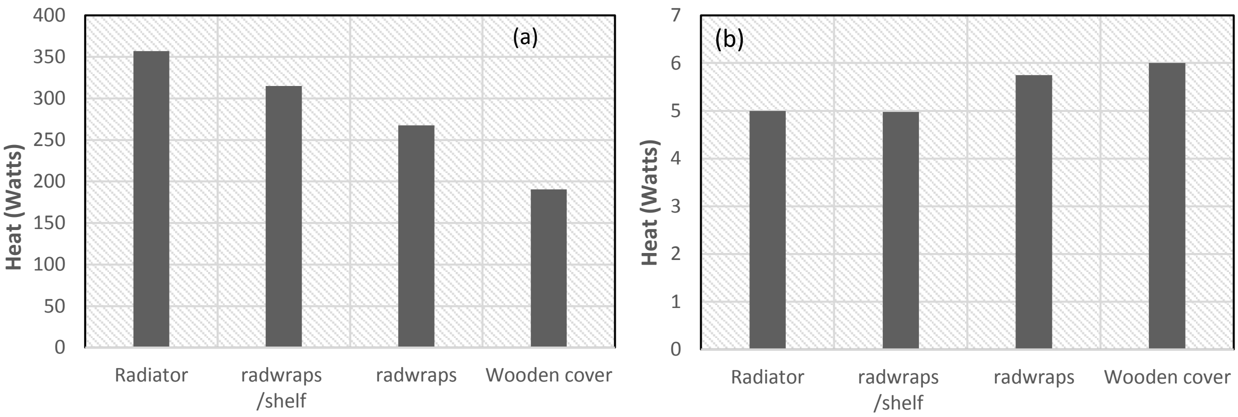


Figure 7: Total heat (a) transfer to the air from the radiator system (convection and radiation) and (b) Loss by conduction through the wall during steady state condition

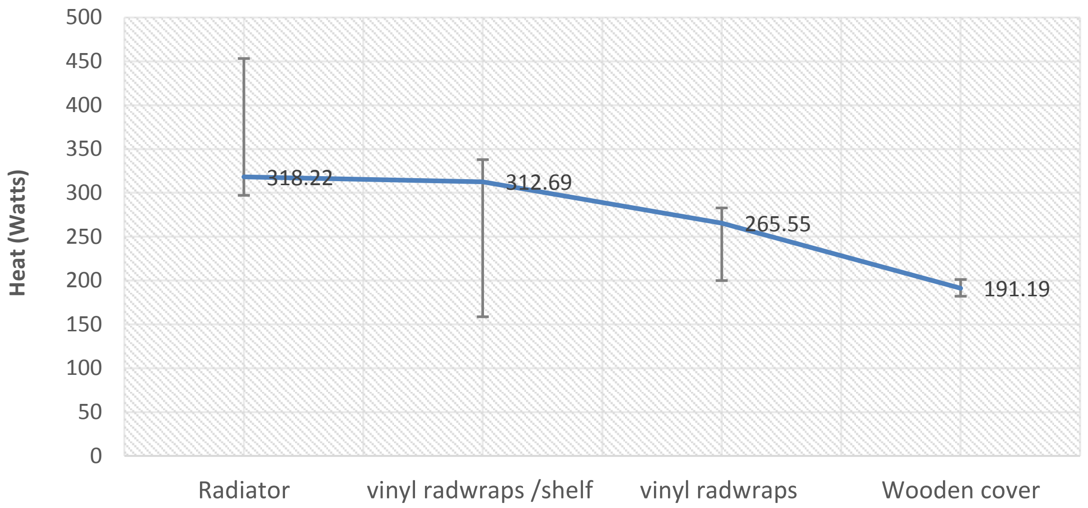


Figure 8: Max, Min (error bar) and Mean of total heat transfer to the air during the testing period

Efficiency of each radiator condition (different scenarios) in term of input/output power has been estimated and calculated from:

$$Efficiency = \frac{output}{input} * 100 \qquad (8)$$

Input heat supplied to the radiators may be calculated from equation 2 with water mass flow of 8.33*10-5m3/s, specific heat capacity of water is 4.2 kJ/kg ^{o}C and water inlet and outlet temperatures (TC1&TC2). Results showed that vinyl radwraps with shelf is working well with 52% efficiency compared with 32% for wooden cover.

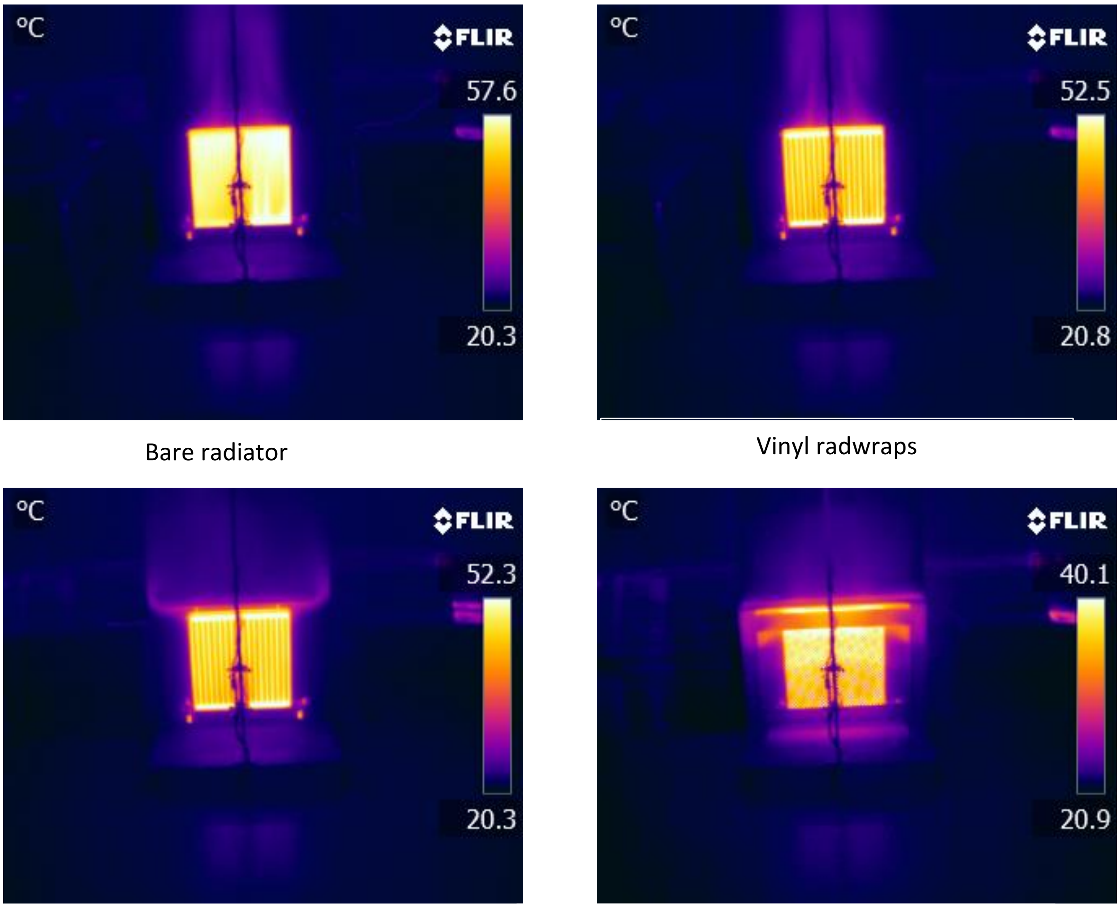
Furthermore, efficiency of each cover relatively to bare radiator or radiator rating power has been assessed (Table 4). Although the radiator is designed on maximum power rating of 833Watts, however it produces only 43% of this under the current condition (Table 4).

Generally, radwraps covered with shelf produces more heat output than the case of radwraps without shelf, as the shelf provides some level of pressure that contributes to increase in the hot air flow. Unlike the case of radwraps without shelf, the air flow has a slow pattern causing the room temperature to take longer time to increase. Another factor of this difference in heat output is that most of the thermocouples in the experiment, were placed in front of the radwraps to detect the temperature pattern. The latter factor can be addressed in future work by evenly distributing the thermocouples in all locations to accurately investigate the heat patterns.

Infrared camera was also used to form an image using infrared radiation to detect the temperature at the surface of each scenario of radiator test (Figure 9) under different condition from the test above using free room. The temperature recorded for each case confirmed the thermocouples reading of hotter radwraps compared with others.

Table 4: Efficiency for each scenarios

Scenario	Actual Efficiency based on input/output heat%	Efficiency compared to radiator power rating%	Efficiency compared to bare radiator %
Bare radiator	60	43	-
vinyl radwraps/ Shelf	52	38	88
vinyl radwraps	45	32	75
Wooden cover	32	23	53



Bare radiator

Vinyl radwraps

Shelf with vinyl radwraps

Wooden cover

Figure 9: Thermal imaging for different scenarios shows the temperature on the surface of bare radiator, Vinyl Rad Wrap, Wooden cover and Shelf with vinyl wraps

When make a measurement of a quantity the result that obtain is not the actual true value of the quantity, but only an estimate of the value. There will always be a margin of doubt about the result of any measurement (Uncertainty of Measurement).

The following are potential sources of uncertainty associated with the radiator system experiment:

a. Measuring instruments: Measurements can be affected by the conditions of the instruments such as drift between calibrations, the effect of aging, and the bias in the instrument. For example, the best estimate of temperature at the radiator surface is 38.39 ^{0}C using thermocouple, but due to uncertainty, the temperature might be as small as 33.570C or as large as 43.61^{0}C. This can be expressed, with its uncertainty, in two different ways:

- Absolute Uncertainty: Expressed in the units of the measured quantity ±0.5 °C.
- Percentage Uncertainty: Expressed as a percentage which is independent of the units ±0.2%.

For other measured parameters the uncertainty will be based on the accuracy range that mentioned in section 3.

b. The effect of Environmental Changes in the operating conditions: such as temperature, pressure and humidity etc. can increase uncertainty. Although the radiator system test maintains the external and internal room environment at the same level for all scenarios, however there could be some level of uncertainty due to infiltration of external air flow through the test room, which varies during the test period and difficult to control.

c. Variation in the measured quantity: Often when measuring any physical quantity its value may fluctuate around the actual estimate. This was the true for condition when measuring the warm air velocity above and in front of the radiator/cover using the anemometer as it requires time to maintain the reading to get the best estimate.

d. Propagation of Uncertainties: Oftentimes multiple values of measured data are combined, each of which has **its own** uncertainty, into a single equation. The way these uncertainties are combined depends on how the measured quantities are related to each other. This type of uncertainty is clearly demonstrated in the present tests when applying the measured data, in series of functional relationships, to calculate the convection heat coefficient. The calculated coefficients were than used to obtain the heat output and the efficiency for each radiator cover scenario. So uncertainties in the input variables will *propagate* through the calculations to an uncertainty in the output.

5. Conclusion

Experimental tests were carried out to investigate the performance of a decorative radiator cover and their impact on heat output. In particular, the radwraps arrangement was compared with traditional wooden cover. Ambient conditions were controlled by constructing an insulated, closed space. Temperatures recording were obtained by thermocouple data logger and thermal imaging camera tests.

From the experiment results obtained for the four scenarios, it can be seen the radwraps/shelf or vinyl radwraps have a smaller effect on radiator heat output than the traditional architectural cover. The radwraps plus shelf provides the greatest output. Though further testing will be necessary to determine all of the actual heat transfer destinations, the tests carried out clearly indicate that in terms of output and contribution to heating the occupied space, the radwraps arrangements provide the optimum output where decorative radiator covers are specified. The Innovative decorative cover, radwraps or radwraps/shelf could results in an extra heat saving compared to wooden cover of 1.85 KWh and 3 KWh a day respectively.

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References

Aydar, E., Ekmekci, I. (2012) Thermal Efficiency Estimation of Panel Type Radiator with CFD Analysis. J. of Thermal Science and Technology. 32, (2), 63-71.

Bangert, K.(2010). Radiator heat transfer augmentation by changes to wall surface roughness and emissivity. Mini-project report.

Beck, S. M. B., Grinsted, S. C., Blakey, S. G. & Worden, K. A novel design for panel radiators. (2004). *Applied Thermal Engineering* 24, 1291-1300.

British Standards Institution (BS EN 442-2:2014 BRITISH). (2014) Radiators and convectors, Part 2: Test methods and rating. ISBN 978 0 580 82034 2.

Department of Energy and Climate Change (DECC). (2012) The Energy Efficiency Strategy: The Energy Efficiency Opportunity in the UK. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65602/6927-energy-efficiency-strategy--the-energy-efficiency.pdf

CIBSE Guide B. (2005) Heating, Ventilating, Air Conditioning and Refrigeration. London, UK.

Dixon, J., C. (2007) The Shock Absorber Handbook, Appendix B: Properties of Air 2nd Edition. Print ISBN: 978-0-470-51020-9, Online ISBN: 9780470516430. 432 pages. John Wiley & Sons, UK

Llana P. (2000) Improved electric heater. Patent EP 1031796 A2.

EIA (Energy Information Administration). (1999) International Energy Outlook, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC, DOE/EIA-0484, UC-950.

Embaye, M., Dadah R.K. AL, Mahmoud, S. (2015) Thermal Performance of Hydronic Radiator with Flow Pulsation – Numerical Investigation, Applied Thermal Engineering, 80, (1-444).

Holmberg, S., Molin, F., Myhren, J.A.(2004) Space heating at low temperature difference between heating unit and ambient air, in: 9th International Conference on Air Distributions in Room, Coimbra, Portugal, September, 2004, pp. 162–163 (book of abstracts).

Holmberg, S. (1984) ‘‘Methods to increase heat transfer from radiators’’ (in Swedish), Tekniska meddelanden 1984:3, KTH.

Long C., Sayma, N. (2009) Heat Transfer. Ventus Publishing Aps, ISBN: 978-87-7681-432-8. Available online at: http://www.leka.lt/sites/default/files/dokumentai/heat-transfer.pdf

Myhren, J.A., Holmberg, S. (2008) Flow patterns and thermal comfort in a room with panel, floor and wall heating, Journal of Energy and Buildings 40(4) 524–536.

Menendez-Diaz, A., Ordonez-Galan,C., Bouza-Rodriguez, J.B., Fernandez-Calleja,J.J. (2014) Thermal analysis of a stoneware panel covering radiators. Applied Energy, 131, 248–256.

Olesen, B.W., Carli, M. de. (2011) Calculation of the yearly energy performance of heating systems based on the European Building Energy Directive and related CEN standards, Energy and Buildings (43), 1040–1050.

Oughton, D, Wilson A. (2015) Faber and Kell's heating and air-Conditioning of buildings, 11th Edition. Routledge Abingdon, Oxen.

Simonson, J.R.1988 Engineering Heat Transfer.2nd edition. MACMILLAN EDUCATION Ltd, London. ISBN: 978-0333-45999-7

Sauter, H. (1985) Leistungsminderung bei Heizkörperverkleidungen, HLH Bd. 36. Nr. 4.

Tu F., Xu, W. et al. (1996) Technologies for Energy Conservation in the Built Environment, The Chinese National Planning Press, Beijing, China. ISBN 7-80058-502-6/T (in Chinese).

Herring, H., Hardcastle, R., Phillipson, R. (1988)Energy use and energy efficiency in UK commercial and public buildings up to the year 2000, Energy Efficiency Series, Energy Efficiency Office, UK, 1988. ISBN 0-11-412903-7.

Jonathan, E.S., Jiang, Z. (1994) China energy databook 1993, lbl-32822, Rev. 2, uc-350, Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, and Energy Research Institute, State Planning Commission of China.

Warren, A. (2002) Towards common energy standards for buildings across Europe, Energy World, No. 297, pp. 8–10.

Appendix: Radiator system component that used in the experiment:

1. Room built from insulation panels
2. Double panel radiator 600x600mm, with maximum power output of 883 Watts.
3. Hot water tank with immersion heater.
4. Cold Water Tank
5. Water pump
6. Copper Pipe 15mm Pipe, connecters
7. Chipboard wall to fix the radiator
8. Flow rate control: Gate Pump Valve 22mm, 15mm Gate Valve, Angled Radiator Valve & Drain Off 15mm x ½" and JG Speedfit
9. Radwraps, radiator wooden cover and shelf
10. Flowmeter to measure the flow rate
11. Thermocouples (TCs) have been located at different locations at the front, back and above of the radiator to record the temperature and also in the middle of the experiment room to measure the room temperature (see Figure 2).
12. 8 channel thermocouple data logger
13. Anemometer to measure warm air velocity emitted from the radiator