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Heat Reflective Layer for Soft Walled Shelters

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Executive Summary

In 2014, the Canadian Armed Forces (CAF) developed a *Defence Operational Energy Strategy (DOES)* that outlines the need of the CAF to improve their defence operational capabilities and sustainability. In an effort to improve operational readiness and resilience and reduce energy supply chain losses, targets were proposed for each of the Department of National Defences' (DND) services. This strategy proposed a "50% reduction of power required by military camps during domestic and expeditionary operations by 2030"[1].

In support of DND efforts to achieve these targets, DRDC engaged NRCan's CanmetENERGY lab in Ottawa to assist with the investigation of innovative technologies as they apply to soft walled shelters. Building upon the findings from the Alternative Energy Laboratory's Deployed ***and Tactical Camp Concepts Recce,*** the concept of pairing a soft walled shelter having an interior reflective layer with an efficient radiant heat source was born. This idea was developed with a goal of reducing the energy required to condition the interior space of the soft walled shelter while improving comfort levels of the shelter's occupants. This report will investigate the applicability of such a layering system to soft walled shelters that are deployed to both high and low temperature environments. Furthermore, the reflective layer's impact on the shelter's infrared signature would also be investigated.

Testing of the reflective layer system has provided details as to the construction of the reflective layer and its use as a textile. Promising layer configurations based on the heat reflective layer and the batting layer have been identified. Furthermore, these layers could be configured according to the shelter's conditioning requirements (whether heating or cooling).

Although the preliminary results are promising further work is required to determine the impact that the reflective layer has on the energy required to condition the shelter interior. A strategy to continue this work is detailed in ***Section 3.4 Next Steps*** which will allow for the heat reflective layer configurations to be tested with the addition of an air space between the reflective layer and the shelter's outer shell.

[1] Labbé, P., Ghanmi, A., Amow, G., Kan, B., Jayarathna, K., Voicu, R., Snook, R., *Evidence Base for the Development of an Enduring DND/CAF Operational Energy Strategy (DOES) DRDC-RDDC-2014-R65*, December 2014.

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Tables and Figures

1. Introduction

In support of DND efforts to consider innovative technologies, DRDC invited the Alternative Energy Laboratory (AEL) at CanmetENERGY in Ottawa to host the ***Deployed and Tactical Camp Concepts Recce*** where energy efficient soft shelter technologies and their supporting heating systems were demonstrated. This demonstration was delivered during the winter in cold weather conditions.

Following this Recce, the concept of pairing a soft walled shelter with a heat reflective layer with an efficient radiant heat source was developed. The aim of this strategy was to reduce the energy required to condition the interior space of the soft walled shelter while improving the comfort levels of the shelter's occupants.

In a cold environment, the heat reflective layer would be applied so that it reflects heat back into the shelter whereas in hot environments the layer would be applied so it reflected the heat way from the shelter interior. This report investigated the applicability of such a layering system to DND's soft walled shelters when deployed in both high and low temperature environments. Furthermore, the reflective layer impact on the shelter's infrared signature also investigated.

This report investigated the TLX Gold Layering system as a heat reflective layer. The selection was based on the properties of the system, the overall affordability of this layering system, and the willingness of the manufacturer to share technical details regarding the reflective material and its use.

This report will describe the following:

- an investigation the heat reflection properties of the *TLX Gold layering system* which is comprised of the following four layers: the heat reflective layer (gold), the insulating batting layer (white), the separator layer (grey), and backing layer (black)
- an understanding of the relative contribution of each of the layers in this system
- recommendations for the application of what has been learned

2. Approach/ Experimental Method

2.1 TLX Gold Membrane System Testing

A variety of tests were conducted to determine the applicability and performance of the TLX Gold system and its application to soft walled shelters. The various tests are described in the three sections that follow.

2.2 TEST 1 – Heat Reflective Layer Tested as the Outer Shell for a Soft Walled Shelter

The TLX Gold Membrane system has been designed to be applied as a retrofit roofing insulation system. A detailed listing of the TLX Gold Membrane performance and properties is located in **Appendix A**. The TLX Gold Membrane system is composed of four different layers: the heat reflective layer, the insulating batting layer, the separator layer and the backing layer (see **Figure 1** below) which are bundled together during the manufacturing process. To facilitate the testing of this layering system, CanmetENERGY was able to purchase theses layers separately, to allow different layer configurations to be investigated.

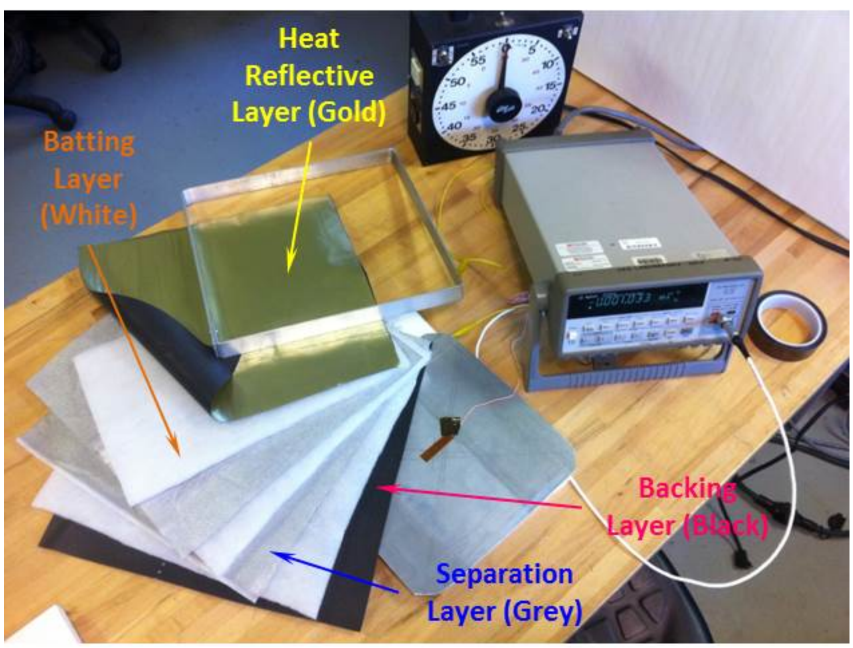

Figure 1: TLX Layers

The manufacturer of the TLX Gold Membrane System recommends that the material be protected from the weather and direct sunlight. Although the product specification suggests that the membrane should be watertight for up to 2 months the manufacturer recommends that the membrane be covered, as soon as possible (see **Appendix A** – **Section A.1 TLX Gold Membrane Details** – Storage and Exposure).

In order to determine how the heat reflective layer alone, would perform when exposed to the weather conditions typically experienced in Ottawa, the outer shell for a soft walled shelter was constructed (see **Figure 2**) and erected on the CanmetENERGY campus in Ottawa. The outer layer for soft walled shelter used during the ***Deployed and Tactical Camp Concepts Recce*** was used as a template, and another shell was constructed using the reflective layer (i.e. the gold layer only) textile.

Figure 2 shows the that the heat reflective layer is facing outward so that it we could determine if the textile delaminates, splits, or deteriorates when exposed to the elements.

Figure 2: Heat Reflective Layer Used as Outer Shell for a Soft Walled Shelter

The soft walled shelter tested at this location from July to October 2016 and the temperature and relative humidity profiles for outdoor and shelter interior can be found in **Appendix A** (see **Figures A1-A3**). During the testing, the average interior temperature was 5.6°C warmer than the exterior temperature and the interior relative humidity was an average of 1.4% higher than the outdoor relative humidity. The warmer interior temperature and higher level of relative humidity is due in part to the lack of venting provided on the outer shell. The outer shell was constructed without the vents to simplify the outer shell's construction.

2.3 TEST 2 – Effectiveness of Heat Reflective Layer

A second round of tests was conducted to determine if the TLX Gold Membrane is able to reflect heat. **Appendix B - Figure B1** is a sketch of the test bench concept which is comprised of a radiant heater, test sample, and an infrared camera (see **Appendix B** – **Figure B1** for IR camera location) and **Figure 3** below shows the completed bench.

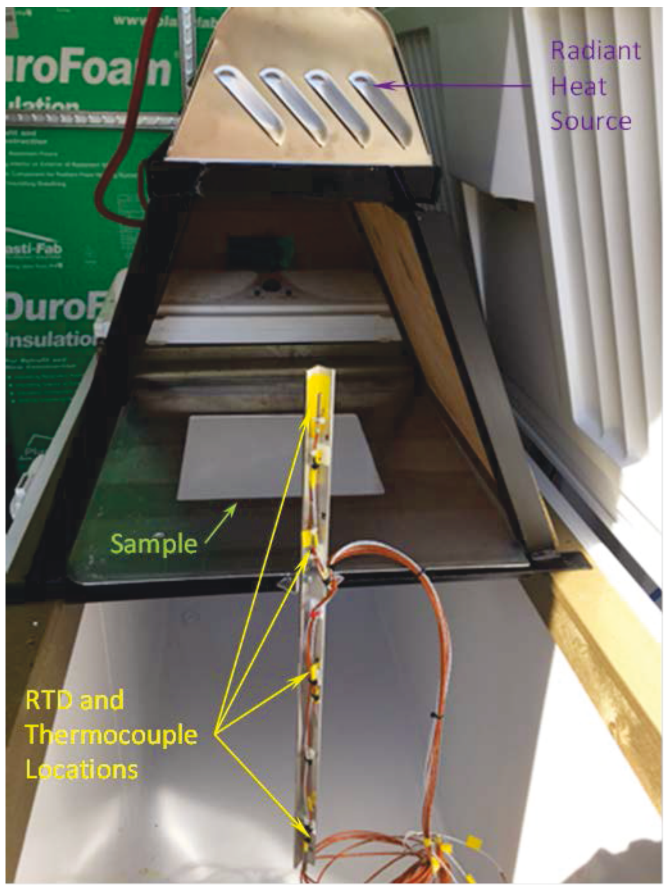

Figure 3: TEST 1 – Test Bench

To verify that the heat reflective layer would reflect heat generated by the radiant heater (located at the top of the assembly) a heat flux sensor was installed onto the underside of the sample being tested. The radiant heater has a controller which allows the amount of power to the radiant heater. Two samples were tested, the first using the heat reflective layer (i.e. gold layer) and the second test was on the backing layer only (see **Figure 1**).

Table 1: Location of Temperature Sensors

LOCATION	HEIGHT (measured from the base of the freezer)	
	(Inches)	(cm)
1	38.5	97.8
2	33.5	85.1
3	24	61
4	15	38.1
5	62	157.5

While the heat flow measurements were being taken, temperatures at were measured by both an RTD and a thermocouple at the locations listed in **Table 1**. **Appendix B – Figure B2** provides a top view of the test bench and **Section B.2 TEST 2 – Heat Flow Sensors** provides details on the heat flow sensor used during testing.

2.4 TEST 3 – Determining the Layer Configuration of the TLX Gold System

The TLX Gold layering system is manufactured as a seven layer system and configured as follows:

Layer 1: heat reflective layer (gold)
Layer 2: batting layer (white)
Layer 3: separator layer (grey)
Layer 4: batting layer (white)
Layer 5: separator layer (grey)
Layer 6: batting layer (white)
Layer 7: backing layer (black)

During Test 3, two sample arrangements were conducted to determine which layer configurations (i.e. both the number of layers as well as their order) and are most effective in reflecting heat. **Figure 4** shows the testing setup used for both Arrangement A and B.

A wooden partition wall was constructed within a cold testing chamber allowing the simultaneous testing of nine samples. A radiant heater was installed directly in front of the samples and an infrared camera was installed on the other side of the partition wall (see **Figure 4**) to capture the performance of the various samples. The radiant heat source shown in **Figure 4** was replaced by an alternate source (see **Appendix C – Figure C1)**.

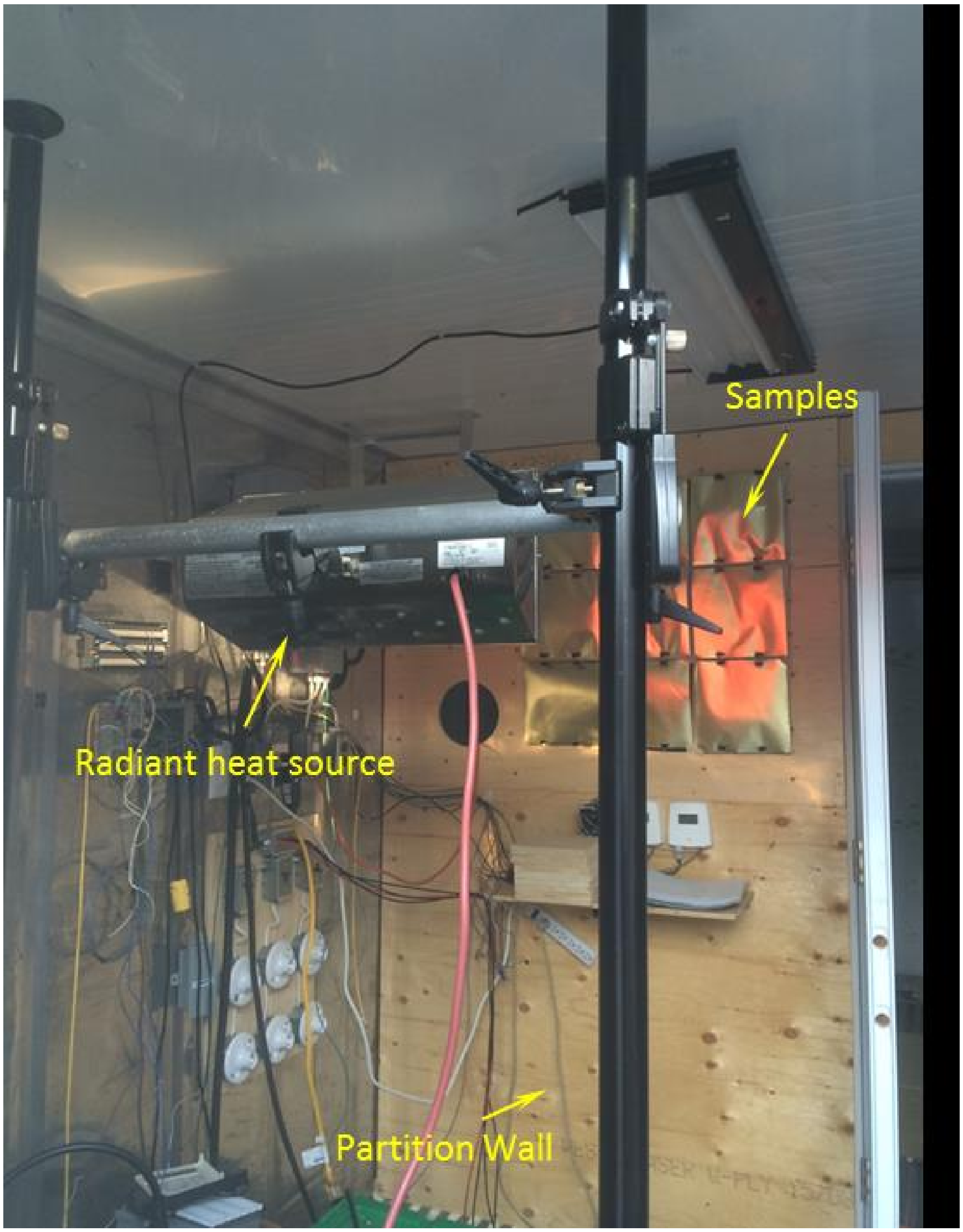

Figure 4: TEST 3 – Set-up for Testing of Layer Configurations

The testing for Sample Arrangement A was conducted in ambient temperature of approximately 17°C. **Figure 5** below provides the details for the nine layer configurations and their position in the partition wall during testing.

Please note that the notation "Reflective Layer REVERSED" indicates when the reflective layer was positioned so that it was not facing the radiant heat source. This configuration is one that may be applied to a shelter that is being cooled.

LAYER CONFIGURATION FOR SAMPLES TESTED		
ARRANGEMENT A		
Sample 9: Reflective Layer Batting Layer Separator Layer Batting Layer Reflective Layer REVERSED	**Sample 8:** Reflective Layer Reflective Layer REVERSED	**Sample 7:** Reflective Layer Batting Layer Reflective Layer REVERSED
Sample 6: Reflective Layer Batting Layer Batting Layer Backing Layer	**Sample 5:** Reflective Layer Batting Layer Separator Layer Batting Layer Separator Layer Batting Layer Backing Layer	**Sample 4:** Reflective Layer Batting Layer Separator Layer Batting Layer Backing Layer
Sample 3: Reflective Layer Batting Layer Backing Layer	**Sample 2:** Reflective Layer Backing Layer	**Sample 1:** Reflective Layer
Note: For each sample, the first layer listed is the layer closest to the radiant heating source.		

Figure 5: TEST 3 – Sample Arrangement A at $T_{ambient}$=17°C

The second test for sample Arrangement B was conducted in ambient temperature inside the cold testing chamber of approximately -20°C. Please note the preliminary findings for TEST 3 – Arrangement A were used as the basis for the selection of the sample configurations for Arrangement B.

Figure 6 below shows the configuration details for the various samples and the sample location within the partition wall during testing.

LAYER CONFIGURATION FOR SAMPLES TESTED		
ARRANGEMENT B		
Sample 9: Reflective Layer only	**Sample 8:** Reflective Layer Reflective Layer REVERSED	**Sample 7:** Reflective Layer REVERSED
Sample 6: Reflective Layer Batting Layer Reflective Layer REVERSED	**Sample 5:** Reflective Layer Batting Layer Separator Layer Batting Layer Separator Layer Batting Layer Backing Layer	**Sample 4:** Reflective Layer Batting Layer Reflective Layer REVERSED
Sample 3: Reflective Layer REVERSED	**Sample 2:** Reflective Layer Reflective Layer REVERSED	**Sample 1:** Reflective Layer only
Note: For each sample, the first layer listed is the layer closest to the radiant heating source.		

Figure 6: TEST 3 – Sample Arrangement B at $T_{ambient}$=-20°C

During TEST 3 – Arrangement B, the following are identical samples:

Sample 1 and Sample 9 (Reflective Layer only)
Sample 2 and Sample 8 (Reflective Layer + Reflective Layer REVERSED)
Sample 3 and Sample 7 (Reflective Layer REVERSED)
Sample 4 and Sample 6 (Reflective Layer + Batting Layer+ Reflective Layer REVERSED).

3. Results & Next Steps

3.1 TEST 1 – Heat Reflective Layer Tested as the Outer Shell for a Soft Walled Shelter

During the construction of the outer shell using the reflective layer of the TLX membrane system, the seamstresses commented that it was quite easy to work with and sew the textile. It should be noted that the reflective layer shell was constructed as an exact duplicate to the original shell for the shelter. This proved to be problematic in that the amount of "stretch" that the original shell fabric provided was more than the TLX textile. This resulted in adjustments to the shelter structure to ease the amount of tension placed on the TLX outer shell. When the TLX textile was stretched the first failure (i.e. splitting see **Figure 7**) occurred on the TLX coating with the black backing textile remaining intact. Should a second TLX outer shell be constructed, an allowance will be recommended to help minimize this problem.

Figure 7: TEST 1 – Splitting of the Heat Reflective Layer (Tensile Stress)

The reflective layer was used as the outer shell for a soft walled shelter from late July to October 2016. During this period, it was exposed to the elements, to determine if it may be appropriate for a typical DND operational setting.

Although, we expect the TLX layer would be applied to the interior of a soft walled shelter and protected from the elements during TEST 1 the reflective layer was exposed directly to the elements (i.e. high winds, rain, UV, etc.) to accelerate the weathering process. Both the temperatures and relative humidity within the shelter and outside were collected. The outside temperatures between 37.8°C and -0.6°C with a relative humidity ranging between 5% and 100%. Similarly, the shelter interior temperatures were measured between 48.3°C and 6.2°C with a relative humidity of between 25.2% and 100%. **Table 2** provides the average monthly difference between the interior and exterior temperature and relative humidity during the testing of the heat reflective layer as an outer shell of a soft walled shelter.

Table 2: Average Temperature and Relative Humidity Differences

MONTH	Average Temperature Difference $ABS(T_{interior} - T_{exterior})$ in °C	Average Relative Humidity Difference $ABS(RH_{interior} - RH_{exterior})$ in %
AUGUST	2.88	11.55
SEPTEMBER	2.62	10.02
OCTOBER	2.06	6.88

The full range of temperature and relative humidity for the testing period is located in **Appendix A** (see **Figures A1-A3**). During this period the layer was monitored for no delamination or separation between the black backing layer to which the gold reflective layer or other deterioration was observed.

3.2 TEST 2 – Effectiveness of the Heat Reflective Layer

The aim of Test 2 was to determine the effectiveness of the various layer configurations to reflect energy. Two tests were conducted using this test bench the first for the heat reflective layer and the second for the backing layer only. The results of this test could provide an indication of the performance of the heat reflective layer since the heat reflective coating is applied to the backing layer.

Figure 8 shows results for both samples, and compares them based on the power (in Watts) to the radiant heater. The results of this test show that more heat generated by the radiant heater was able to pass through the backing layer than the reflective layer. **Appendix B** contains **Figures B3 and B4** which show the temperatures as well as the heat flow measurements for each of the samples tested. Also, an IR camera captured the testing of the two samples. The .MOV files have been included in **Appendix C** (see **Section C.2 IR Camera** for memory stick) provided with this report.

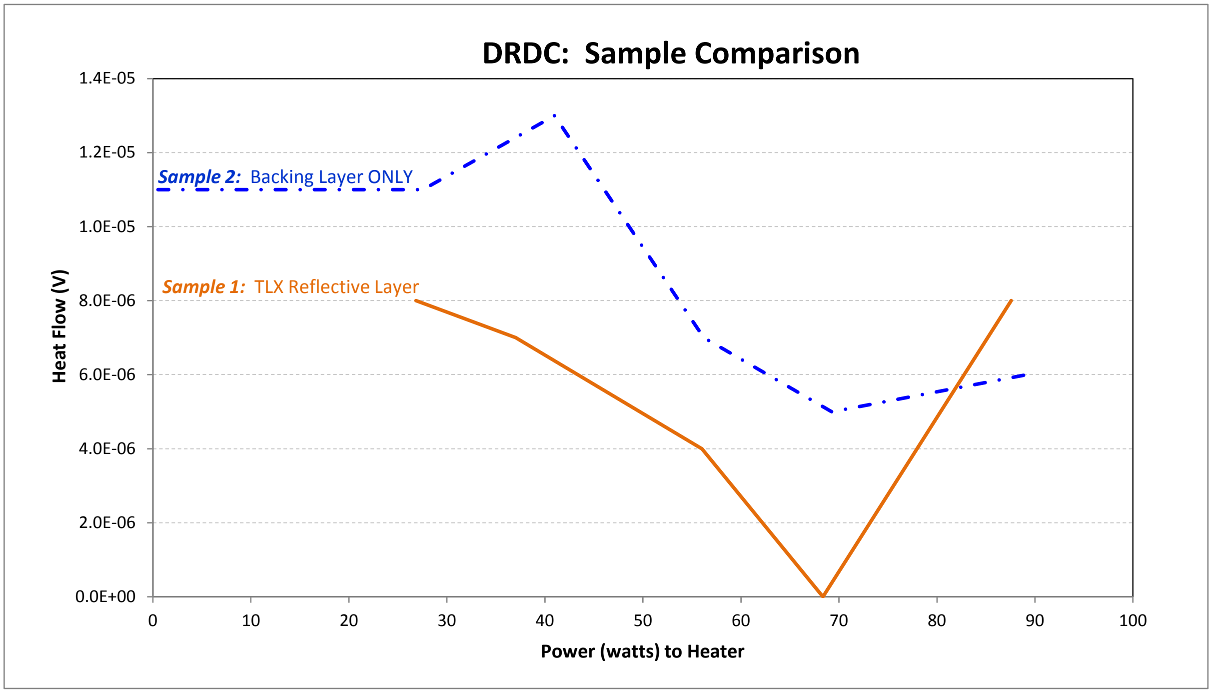

Figure 8: Comparison of Backing Layer with Heat Reflective Layer

While conducting TEST 2, it was discovered that the radiant heater used in this testing bench did not provide a uniform radiant heat across the sample surface. Since the samples are tested individually, there is no way to ensure that the layering samples were exposed to the same radiant heating profile. It is for this reason that the heat flow values (in W/m^2) have not been calculated. The voltage values are shown in **Figures 8, B3 and B4** because the voltage is directly proportional to the heat flow and provide an indication of the relative performance for the layers.

An alternate radiant heat source that could provide a more consistent, uniform heating profile was selected but the test bench for TEST 2 could not be adjusted to accommodate this heater. In order to allow various layering configurations to be compared, TEST 3 setup was developed in an effort to minimize the challenges confronted in TEST 2 and propose layering configurations appropriate for soft walled shelter where the interior is either heated or cooled.

Clearly, **Figure 8** shows that the reflective coating applied to the backing material is able to reflect some of the heat energy. Using the results from the various test with the non-uniform heat source had the reflective heat layer absorbing approximately 15-20% less energy than the black backing layer. It is expected that heat reflective layer may be able to exceed this percentage but more testing will be required to confirm this.

3.3 TEST 3 – Determining the Layer Configuration of the TLX Gold Layer System

In order to avoid some of the challenges encountered in TEST 2, TEST 3 allows for the simultaneous testing of nine sample layer configurations as presented in **Section 2.4**. Also, the radiant heater used in TEST 2 (see **Figure 4**) was replaced by a tank-top radiant heater which provided a more uniform distribution of heat across the samples being tested (see **Appendix C – Figure C1**).

When considering a heat reflection layer for the use of DND in an operational setting, the additional costs and logistics required for the transportation of such a system can adversely affect their integration. This test sets out to determine which layer configurations (i.e. both the number of layers as well as their order) and are most effective in reflecting heat while having the least amount weight and volume. Therefore, when considering the TLX Gold membrane system which consists of seven layers, the goal of finding the minimum number of layers that would provide the heat reflection while minimizing the IR signature of the shelter was the priority.

For the testing of both Arrangement A and B, the TLX Gold seven layer system was positioned in the middle of the nine samples tested to serve a benchmark which facilitated the comparison of the sample performance. The sample layer configurations for Arrangement A ranged between one layer (heat reflective only) up to five layers (using combinations of all four layers). TEST 3 – Arrangement A was conducted in an ambient temperature of 17°C, and video take with the infrared camera is provided in **Appendix C – Section C.2** (see file *D:\DRDC_TEST3_T_17C\ oct 4 set 2 part 2 timecode.wmv*).

TEST 3 – Arrangement A simultaneously tests nine layer configurations in an ambient temperature of approximately 17°C. **Figure 9** allows for the qualitative comparison of the various sample layer configurations. It should be noted that, Sample 9 (located in the upper left hand corner of the image) was not install properly and this result should be not be considered.

Figure 9: TEST 3 – Arrangement A Image from Video (Time: 00:05:09;06)

Figure 9 shows that Samples 2, 3, 4, 6, 7 and 8 (which have a minimum of 2 layers to a maximum of 4 layers) to are quite similar in their performance. Sample 1 which consists of the reflective layer only is performs quite poorly when compared to the other samples.

These results were the basis for the selection of the layer configurations for TEST 3 – Arrangement B. The sample layer configurations for Arrangement B were simplified to included different configurations of the reflective layer and the batting layer only.

Figure 10 below is taken when Arrangement B was tested with an ambient temperature of -20°C. These results can be found on the memory stick provided in **Appendix C – Section C.2** (see file *D:\DRDC_TEST3_T_-20C\01_minus 20 first run 13oct16 11-16-15 timecode.wmv*). The figures marks labels for each of the sample layer configurations (see black numbers) which correspond to those detailed in **Figure 6**. Also, to facilitate the comparison of the various layer configurations, the IR camera was setup to provide temperatures for five of the samples.

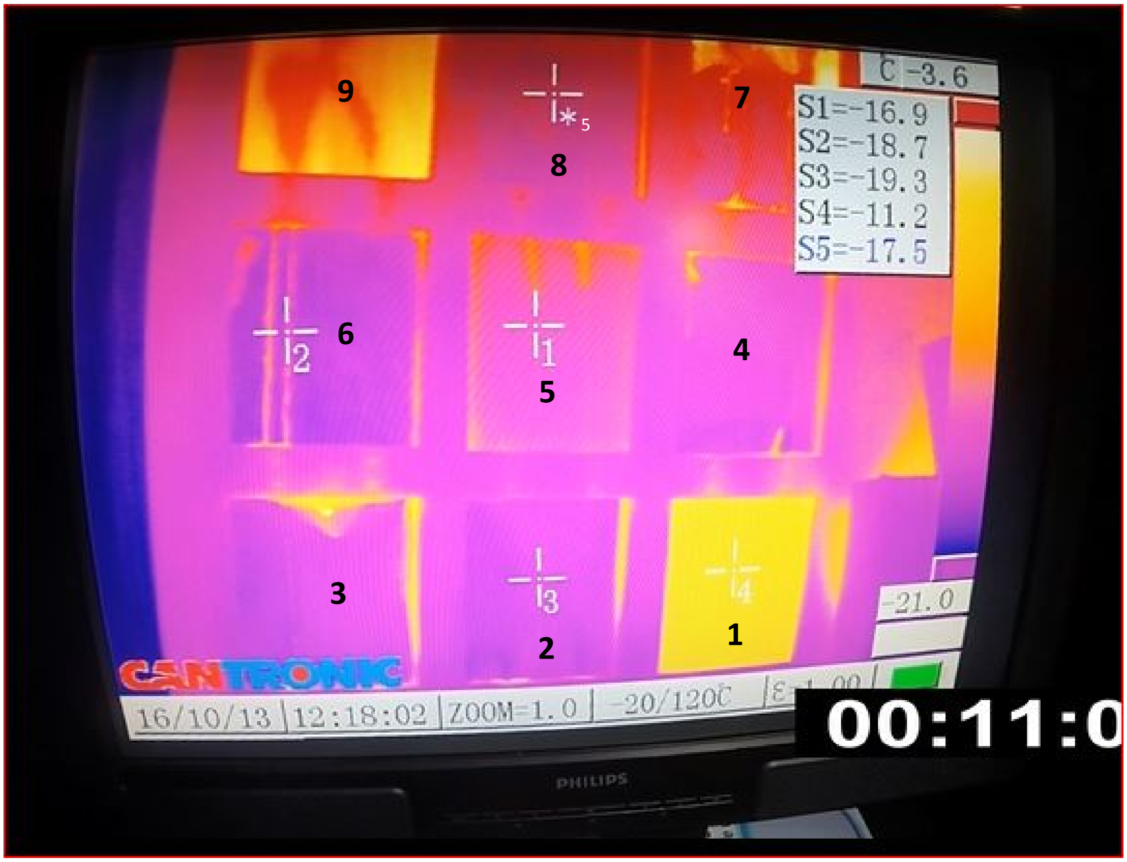

Figure 10: TEST 3 – Arrangement B Image from Video (Time: 00:11:01;01)

Figure 10 shows five points were temperature readings were taken by the IR camera (see the cross-hairs and labels in white). According to the readings measured by the IR camera (see the upper right hand corner of Figure 10). Unfortunately, these values can only be used for the samples that do not include the Reflective Layer REVERSED (i.e. sample layer configurations 1, 5, and 9).

During TEST 3 the IR camera is set to an emissivity of 1.0 (see **Figure 10** the lower right hand Ɛ=1.00) and samples 2, 3, 4, 6, 7, and 8 have the Reflective Layer REVERSED facing the IR camera which requires the emissivity (Ɛ) to be set to 0.16 (see **Appendix A – Section A.1 TLX Gold Membrane Details and Installation**). Unfortunately, the IR camera cannot be configured to accept more than one emissivity within the same image. Also the overall configuration of the test could not accommodate the installation of a second IR camera.

During the various tests conducted with the various layering configurations, the heat reflective layer does appear to provide an "averaging effect" whereby a heat source is not as easily identifiable using the IR camera. Also, it should be noted that the reflective layer cannot be in direct contact with a heat source or this averaging effect will no longer occur.

3.4 Next Steps

One of the challenges encountered in this project has been to quantitively determine the benefits of the reflective layer. Following the challenges faced in conducting TESTS 1-3, investigation on instrumentation to facilitate collection of data to measure the effectiveness of the reflective layer was conducted. The use of a mannequin dummy which is able to provide an index for comfort that takes into account the rate of metabolic heat generation, clothing insulation, and air movement over the body and the processes of heat transfer by radiation, conduction, convection and evaporation[2] was investigated. Unfortunately, the costs associated with the acquisition of the mannequin proved to be prohibitive. Further investigation uncovered *operative temperature transducers* (see **Appendix C – Section C.3 Next Steps**) which can be used in the place of a mannequin dummy. More specifically, both the transducer and mannequin have the following characteristics:

- The same convection to radiation heat loss ratio
- The same angle factor to their surroundings
- The same absorption factor (emissivity) for long and short wave radiation.

The operative temperature transducer is light grey ellipsoid shape, approximately 160 mm long with a diameter of 54 mm which is able to measure the average surface temperature. The transducer is able to simulate a person's angle factor to their surroundings (i.e. typical positions when a person is sitting, standing or lying down). Typically, an operative temperature transducer is heated to the same temperature as the surface temperature of a person's clothing and the dry heat loss from the body can be obtained measured directly.

When evaluating human comfort in a given environment, the equivalent temperature is of interest since it provides the conditions where a person feels thermally comfortable. ISO 7730 and ISO 7726 provide guidelines for the evaluation of thermal comfort and suggest the collection of the following data:

- Operative temperature and air velocity
- Dry heat loss
- Radiant temperature, air temperature and air velocity

Also, the ISO 7730 guideline suggests the thermal comfort for a sedentary activity (we are assuming the shelter would be used primarily for sleeping) provide the following conditions:

- The relative humidity should be between 30% and 70%
- Vertical temperature difference between the typical ankle and head heights should be less than 3°C
- Radiant temperature asymmetry from cold surfaces (typically windows) should be less than 10°C
- Radiant temperature asymmetry from warm ceilings should be less than 5°C
- Draught rate less than 15% at the typical neck and ankle heights

[2] King, D., *Design Masterclass 7 Operative Temperature, Thermal Comfort*, CIBSE Journal, June 2011, p. 52-54.

In order to determine if the application of a reflective layer system to the interior of a soft walled shelter is effective in reducing the energy required to condition the interior space of the soft walled shelter, it is recommended that operational temperature transducers be used. Also, we anticipate that the set-point for the radiant heater will be lower than that typically used for the shelter heating since the operative temperature transducer will be able to indicate when the occupant is comfortable.

It is proposed that two identical soft walled shelters be erected both having an outer shell fabricated from the same textile as that used by the Canadian Armed Forces' soft walled shelters. One of the shelters would be erected with the outer shelter only and the second shelter would have the reflective layer system installed to its interior. An operational temperature transducer would be installed in each of these shelters to simulate a person in a sitting, standing and lying down positions.

This testing configuration will allow for the addition of an air space between the shelter outer shell and the reflective layer which has not be simulated to-date. It is expected that this air space can provide additional benefits to the overall performance particularly when a heat reflective layer is used in the REVERSED configuration (or in air-conditioning mode).

Lastly, the two soft walled shelters described above should be evaluated for the following:

- Uniformity of interior temperature profile (i.e. stratification of temperature)
- Ability of the mechanical system (i.e. providing heating or cooling) to maintain a stable thermal environment (where one shelter would be assisted by the heat reflective layer system)
- Thermal discomfort felt by the occupants (using ISO guidelines described earlier in this section).

These parameters will the used as the basis to determine the occupant's comfort level, and the energy required by the shelter's mechanical system to condition the space will provide the basis to determine the effectiveness of the heat reflective layer. Also, while testing is being conducted, each shelter will have a dedicated IR camera (where the emissivity can be adjusted as necessary) that will capture the signature during the testing.

4. Conclusions

Testing of the reflective layer system has provided details as to the construction of the reflective layer and its use as a textile. Also, this report has identified a promising layer configuration based on the use of the heat reflective and the batting layers. These layers would be configured according to the shelter's conditioning requirements (whether heating or cooling).

Although the preliminary results for the heat reflective layer are promising, further work is required to determine the impact that the reflective layer has on the energy required to condition the shelter interior. Details provided in **Section 3.4 Next Steps** provide a strategy to continue testing the heat reflective layer, the batting layer with the addition of an air space and the textile used by the CAF for its soft walled shelters. The use of operative temperature transducers during testing will provide the data necessary to determine the effectiveness of the heat reflective layer when applied to the interior of a soft walled shelter.

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Appendix A: TEST 1 – Reflective Layer as the Outer Shell

Appendix A contains the performance specification for the TLX Gold Membrane provided by the manufacturer. Also, the temperature and relative humidity profiles measured when the reflective layer was used as an outer shell for a shelter have been provided.

A.1 TLX Gold Membrane Details and Installation

TLX Gold

Technical Data

Width (effective)	1200	mm
Flap	100	mm
Length	10	m
Thickness	33	mm
Yield	12	m^2
Weight	900	g/m^2
Core R value ($R_{90/90}$)	0.85	m^2 K/W
Emissivity	0.16	
Vapour resistance	0.50	MN s/g

Packaging Data

Bag length	1.3	m
Bag diameter	0.4	m
Bag weight	11	kg
Bags per pallet	15	

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TLX Gold measured data

Performance			
Emissivity	0.16		
Fire	Class E	EN 11925 - 1	UKAS
Moisture transmission Top breather membrane	0.21 MN s/g MVTR:975 g/m² 24hr	BS EN 3177	UKAS
Moisture transmission Bottom reflective layer	S_d 0.03m MVTR: 1336 g/m² 24hr	EN ISO 12572	UKAS
Core R-value	0.85 m²K/W	EN ISO 8301:1991 (BS EN 12667:2001)	UKAS

Structure			
Thickness	33mm	Composite layers	7

Pack information			
Roll width (excluding flap)	1.2m	Roll length	10.0m
Overlap flap	0.1m	Roll weight	11kgs

Minimum thickness of additional insulation with TLX Gold

	Target U-value W/m².K		
	0.20	0.18	0.16
Foiled rigid insulation (0.020W/mK)	95mm	110mm	130mm
Glass wool (0.032W/mK)	130mm	150mm	175mm
Glass wool (0.035W/mK)	140mm	160mm	190mm

THERMAL HOTLINE

TLX™ 01204 674730

GENERAL INSTRUCTIONS

- These installation instructions assume uniform rafter centres of 400mm or 600mm and that any battening applied to the roof is of a suitable size to avoid movement or rocking of the battens over the top of the TLX Gold. If these assumptions do not apply, the TLX Hotline (01204 674730) should be contacted for advice.
- Protective clothing is not required when handling TLX Gold.
- TLX Gold must be installed with the Gold side facing into the building.
- Bare electrical wiring must not be allowed in contact with TLX Gold. PVC coated electrical wiring to normal domestic items such as light fittings may come into contact with TLX Gold.
- If electrical cables are surrounded by insulation they may need to be de-rated and guidance should be sought from an electrician.

INSTALLATION - NO COUNTER BATTENING

- TLX Gold may be fitted without a counter batten when there is at least a 50mm void available at the top of the rafters for the product to drape into. If there is less than 50mm of space available the product will need to be fitted taut with a 38mm counter batten.
- The right hand side of TLX Gold is fitted in place with nails or staples of at least 20mm. TLX Gold is then unrolled across the rafters. The TLX Gold should sag between each rafter centre, so that when the tiling battens are fitted there is a clear 10mm channel formed between the underside of the tile batten and the TLX Gold to allow for water runoff and air movement.
- Side laps at the end of runs are created by separating the breather membrane layer from the rest of the product. The insulation layers are then cut back to the last rafter that the material has crossed. A new roll is then laid from where the cut back material ends. The created membrane flap then laps onto the new roll and is sealed with a suitable tape to create a watertight finish.
- Each layer of TLX Gold must butt join the previous layer, with the membrane overlap running onto the lower layer, thus ensuring that any water runs down the roof slope without penetrating between the layers. The overlap is then sealed by removing the release paper from the integral tape on the TLX Gold and bringing the lap in contact with the lower layer. The drape should be consistent for each layer of TLX Gold.
- A 10mm draped channel should run above the TLX Gold, up the centre of each rafter space, to allow water to run down and for air movement. If a clear channel is not formed, 10mm spacers or a length of 10mm diameter pipe may be fitted to introduce a drape.
- The membrane overlap on the bottom layer of the TLX Gold should extend onto a suitable eaves protection system. The TLX Gold should be sealed to the eaves protection system to avoid introducing air movement below the TLX Gold.
- TLX Gold is permanently held in place by tiling battens and tiles are fitted in accordance with BS 5534. If there is any doubt about the water tightness at the fixing point butyl tape or a bead of bitumen adhesive may be applied to give an improved seal.

INSTALLATION WITH COUNTER BATTENING

- The right hand side of TLX Gold is fitted in place with nails or staples of at least 20mm. TLX Gold is then unrolled tightly across the rafters parallel to the eaves.
- Side laps at the end of runs are created by separating the breather membrane layer from the rest of the product. The insulation layers are then cut back to the last rafter that the material has crossed. A new roll is then laid from where the cut material ends. The created membrane flap then laps onto the new roll and is sealed with a suitable tape to create a watertight finish.
- Each layer of TLX Gold must butt join the previous layer, with the membrane overlap running onto the lower layer, thus ensuring that any water runs down the roof slope without penetrating between the layers. The overlap is then sealed by removing the release paper from the integral tape on the TLX Gold and brings the lap in contact with the lower layer.
- The membrane overlap on the bottom layer of the TLX Gold should extend onto a suitable eaves protection system. The TLX Gold should be sealed to the eaves protection system to avoid introducing air movement below the TLX Gold.
- TLX Gold is permanently held in place with 38mm deep counter batten, then tiling battens and tiles are fitted in accordance with BS 5534. If there is any doubt about the water tightness at the fixing point butyl tape or a bead of bitumen adhesive may be applied to give an improved seal.

CUTTING

- TLX Gold can be cut using a sharp pair of scissors such as 10" carpet fitter scissors. TLX recommend Kretzer Finny 74525.
- Pieces that have been cut should be sealed, stapled and battened as soon as possible and should not be left unsecured overnight.
- Up stands (such as dormers, abutments and dormer cheeks) should have the membrane separated from the insulation layers so as to create an up stand of membrane that provides a watertight finish. This up stand should be stapled, taped and battened immediately.
- Any small tears or holes should be patched with tape. Larger holes should be patched with a piece of breathable underlay.

TAPING

- TLX Gold is supplied with an integral tape across the top length of the roll to seal the horizontal overlaps.
- Side laps of the material should be sealed using a high tack acrylic adhesive such as Gawler Airtight tape.

AIR LAYERS

- Unventilated air layers form an important part of the TLX Gold insulation system. If the air spaces are omitted the overall thermal performance will be significantly reduced.

EXPOSURE

- The membrane layer of TLX Gold should be watertight for up to 2 months exposure, but the product should be covered as soon as possible by the roof covering.

ADDITIONAL INFORMATION

- Install additional insulation according to the manufacturer's instructions.
- Provide air gaps between TLX Gold and additional insulation as required.

STORAGE

- TLX Gold rolls must be stored on a dry flat surface, protected from the weather and direct sunlight.
- Make sure when installing TLX Gold that it does not come into contact with heat sources above SOC. Penetrations for heat sources above this temperature should be in compliance with Approved Document J of the Building Regulations.

VAPOUR CONTROL AND VENTILATION

- A vapour control layer is not required for any of the recommended solutions. For some bespoke solutions it may be necessary to include one.
- A well-sealed ceiling in line with BS 5250, is essential to prevent large amounts of water vapour from entering the roof space through air movement.
- Ventilation of the space between the TLX Gold and the outer roof covering is not required for air open roof coverings such as clay or concrete tiles and rough natural slates. Smooth slates and sealed roof systems such as metal roofs will require additional ventilation of this space. If there is any concern about the classification of the covering, advice should be sought from the manufacturer.
- If in any doubt about harmful condensation, contact TLX Insulation for guidance.

TLX Hotline (01204 674730}

A.2 TEST 1: Heat Reflective Layer Used as the Outer Shell for a Shelter

Figures A1-A3 shows the measured temperatures and relative humidity for both the exterior and shelter interior during the months of August, September and October 2017, respectively. Please note that the sensor measuring outdoor temperature and relative humidity failed and the relative humidity and temperatures shown were taken from a weather station located 200m from the test hut.

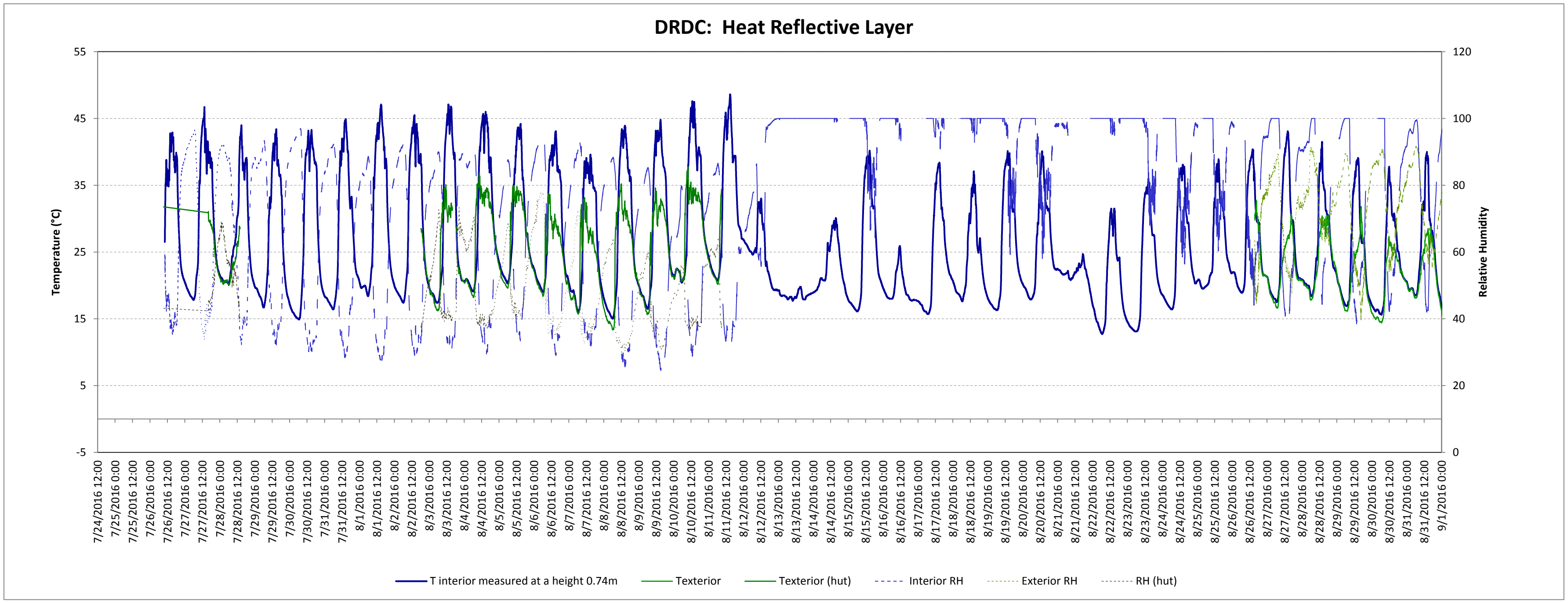


Figure A1: TEST 1 – Heat Reflective Layer as Shelter Outer Layer Testing July (August 2016)

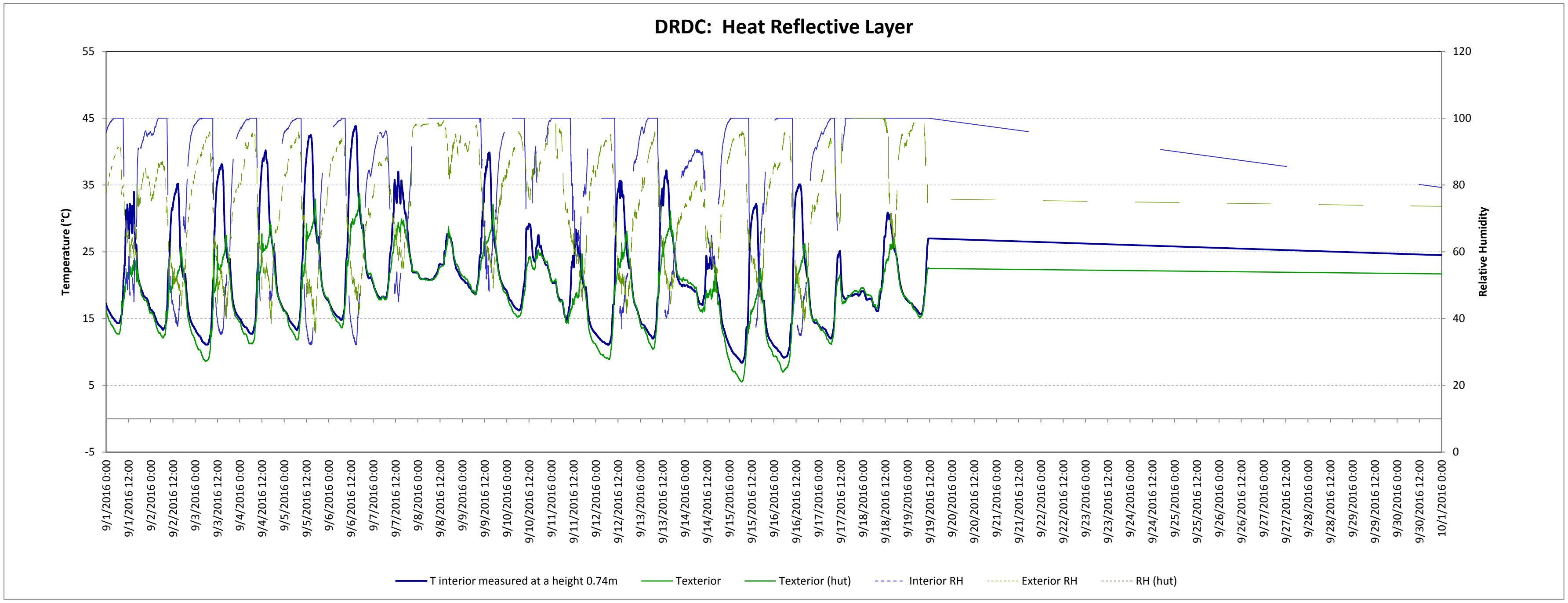


Figure A2: TEST 1 – Heat Reflective Layer as Shelter Outer Layer Testing (September 2016)

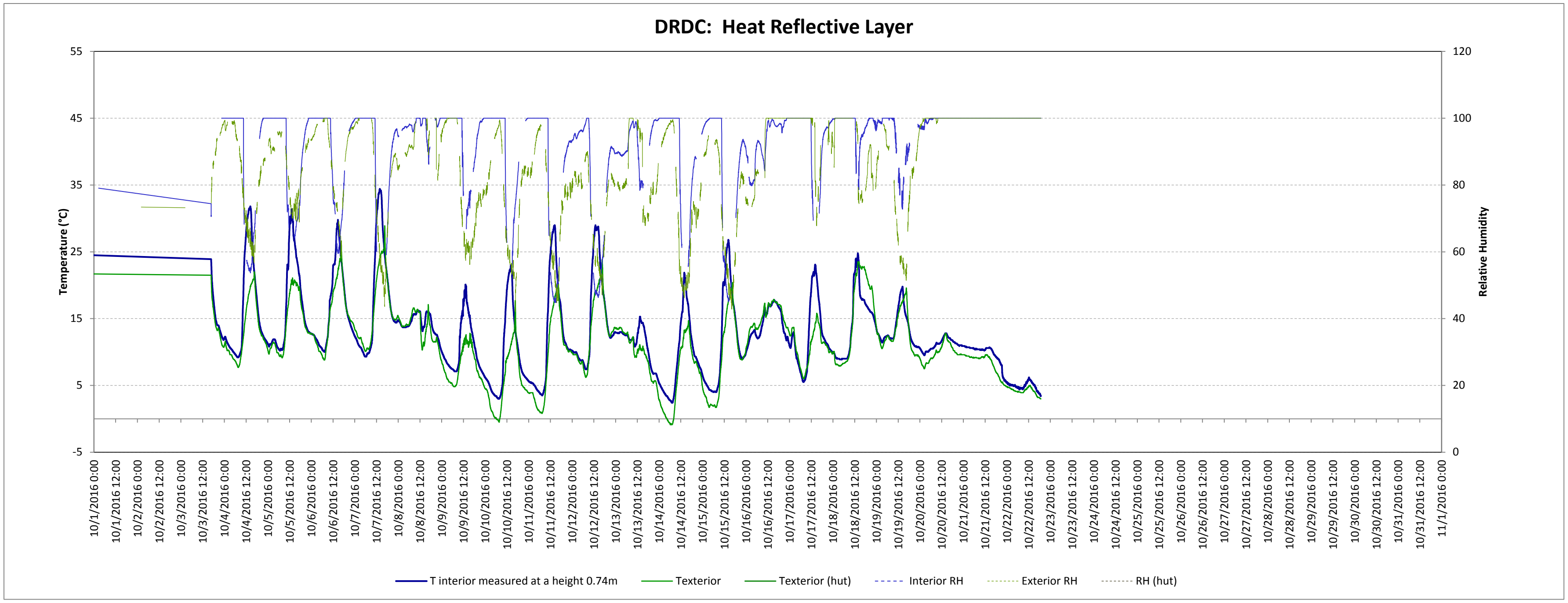


Figure A3: TEST 1 – Heat Reflective Layer as Shelter Outer Layer Testing (October 2016)

Appendix B: TEST 2 – Heat Reflection of TLX Layer

Appendix B provides details for TEST 2 setup and the results reported when measuring heat flow for a backing textile, and the backing textile with the heat reflective layer. Also included is the specification for the heat flow sensor used for this test.

B.1 TEST 2 – TLX Reflective Layer Testing

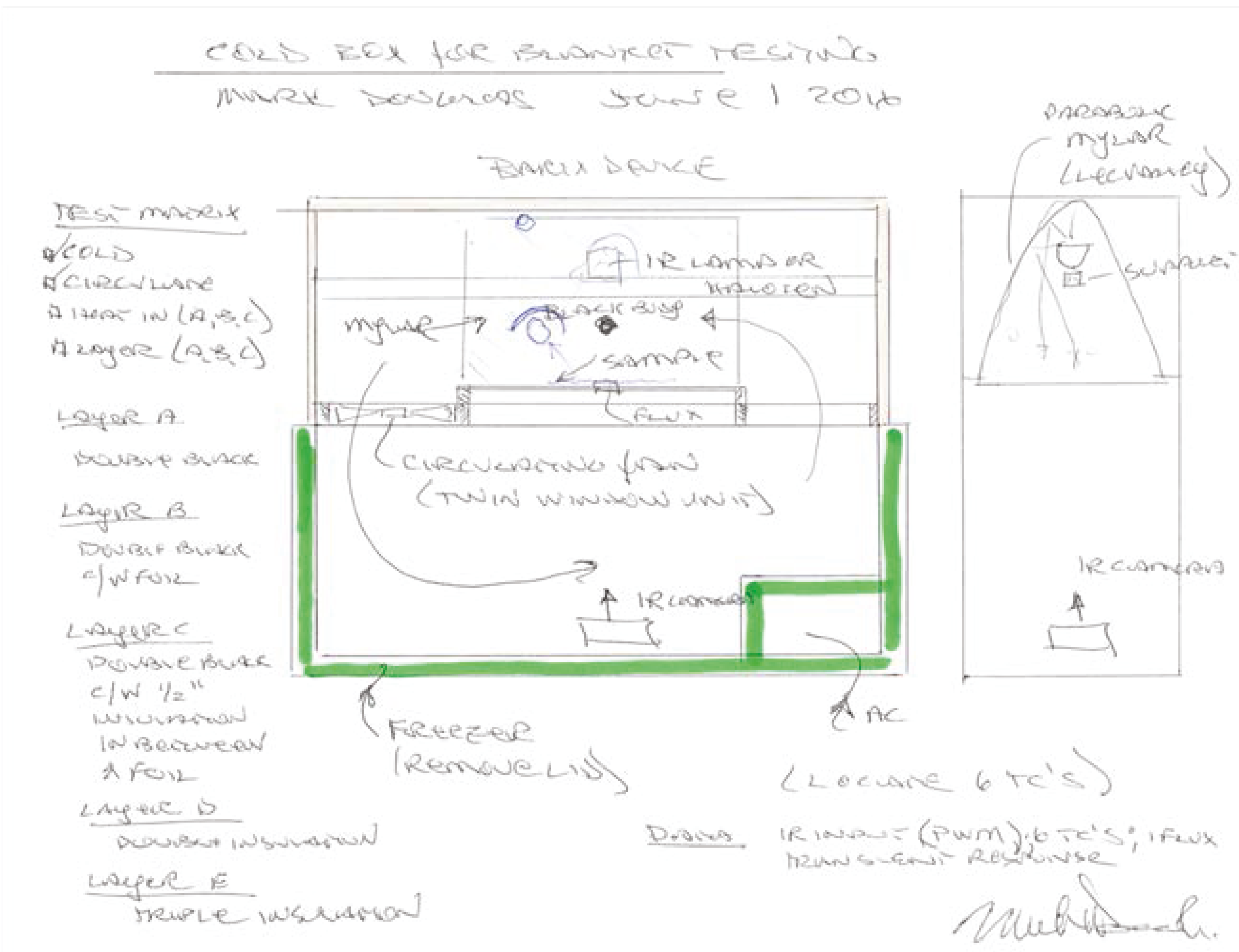


Figure B1: TEST 2 – Bench Concept

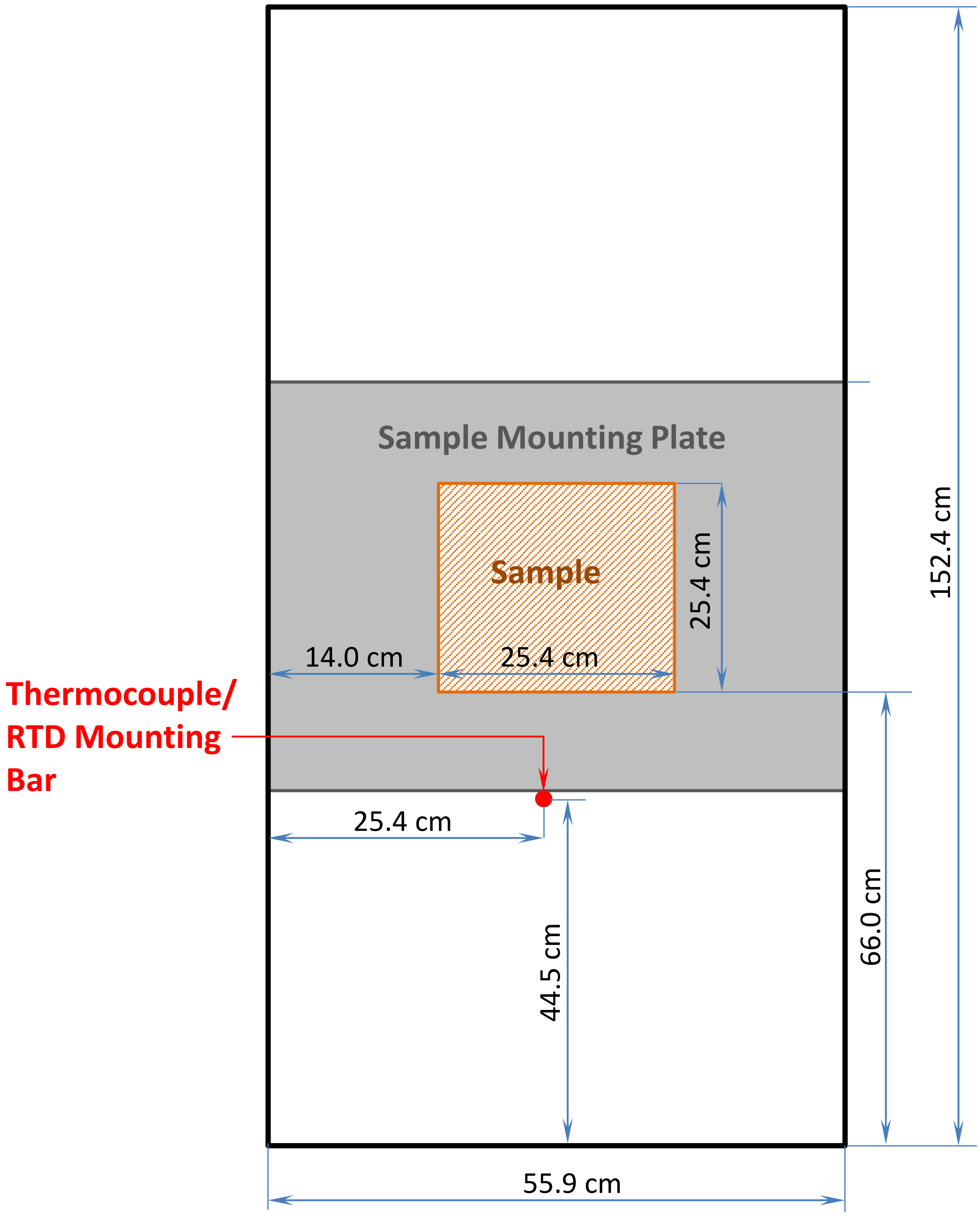


Figure B2: TEST 2 – Top View of Test Bench

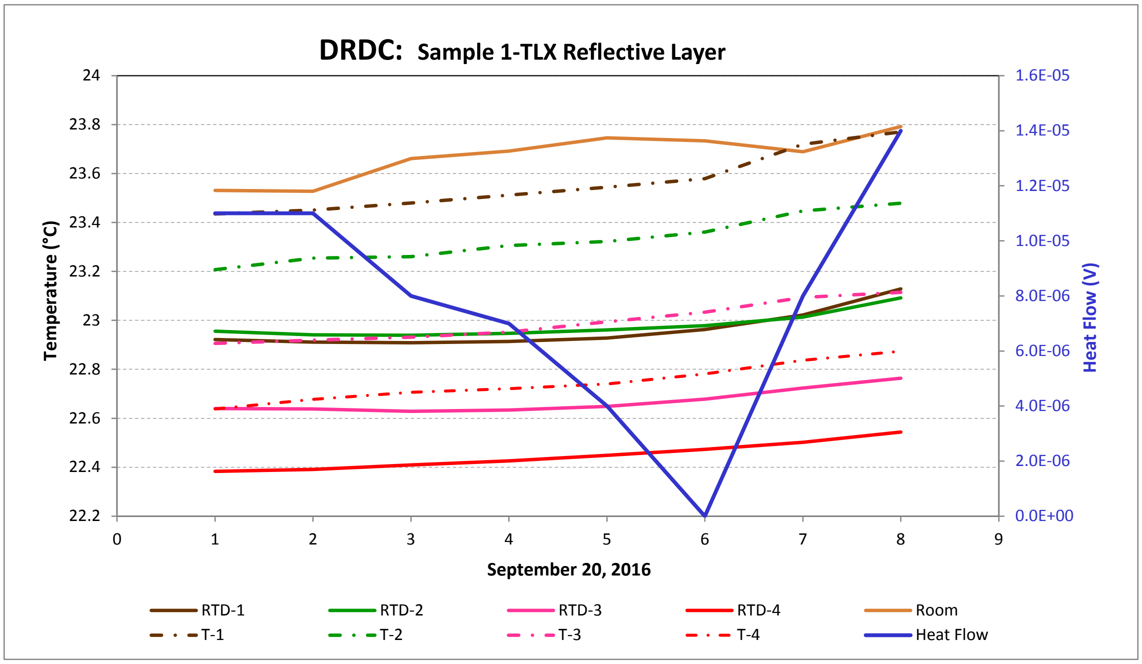


Figure B3: Temperature Profiles and Heat Flow

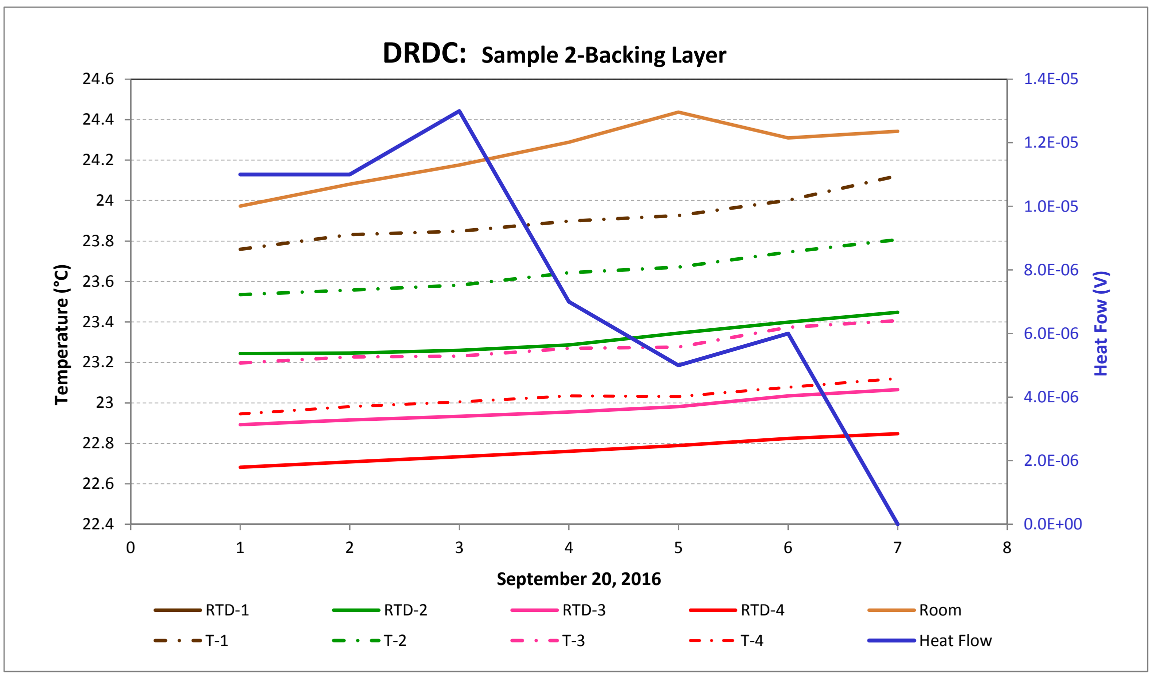


Figure B4: Temperature Profiles and Heat Flow

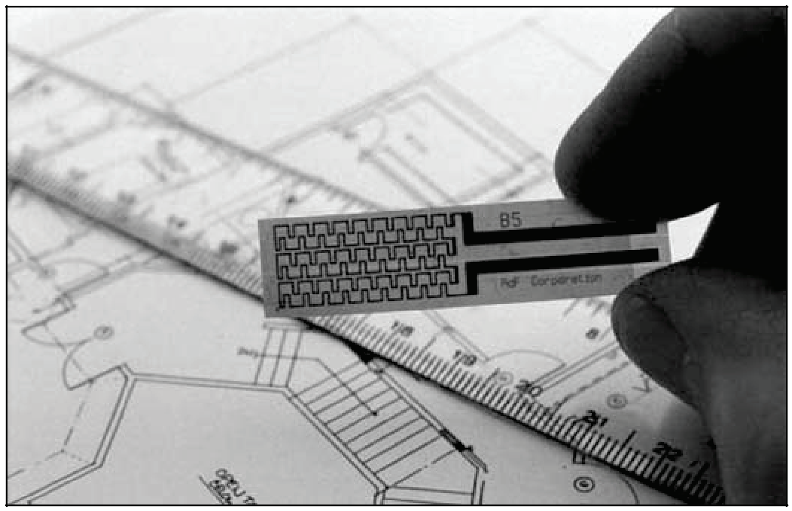
B.2 TEST 2 – Heat Flow Sensor Details

RdF

Simplified
Heat Flow Measurement

[redacted]

There are many instances where it is desirable to measure heat flow instead of or in addition to temperature. The use of Micro-Foil® heat flow sensors simplifies the measurement of heat flow wherever accurate data on heating or cooling rates is required. This discussion will focus on the Micro-Foil® type sensors. The unique construction of Micro-Foil® sensors provides an easy-to-attach surface sensor with the lowest thermal capacity, fastest response time and least disturbance to heat flow. Typical applications for heat flow sensors exist in industries such as plastic, machinery, paper and automotive and they are also used in heat transfer studies such as determining the thermal properties of insulation systems. Heat flow sensors are also being used in energy management of buildings. These unique sensors have been used on every major space program, providing accurate data on structural heat transfer, heat shield performance, ablation studies, and aerodynamic wind tunnel studies.



Construction & Principles of Operation

The Micro-Foil® heat flow sensor is a differential thermocouple type sensor which utilizes a thin foil type thermopile bonded to both sides of a known thermal barrier as shown in **Figure 1**. The difference in temperature (D**T**) across the thermal barrier is proportional to heat flow through the sensor. Thermoelectric junctions are formed from materials "A" and "B" on the upper surface of the barrier. In series with these are corresponding junctions mirror imaged on the lower surface. This construction results in an equal number of junctions on the upper and lower surfaces. The two output leads are of the same material, with one coming from the first junction on the upper surface and the other from the last junction on the lower surface.

In actuality, only one pair of junctions is required for a completed sensor; however the output signal and sensitivity are directly proportional to the number of paired junctions.
Each pair of upper and lower junctions forms a differential thermocouple with voltage output proportional to a small D**T**. Multiple pairs of junctions in series are used to increase signal and

resolution. This assembly is called an in-depth thermopile because heat flows in series through a barrier from hot to cold junctions.

The output signal represents local heat transfer where the sensor is mounted. The sensor is placed in intimate contact with the surface or body for which heat transfer rates are desired. The same energy must pass through the sensor as is associated with the surface to which it is attached. Any time thermal energy passes through a material — in this case the thermal barrier — a temperature gradient D**T** is generated. This gradient is directly proportional to the magnitude of the thermal energy flowing through the barrier—*the heat transfer rate*.

The factors that effect the magnitude D**T** are the heat transfer rate (**Q**), thickness of the barrier (**S**), and the thermal conductivity (**K**) of the barrier material. The following simplified expression is given showing the relationship between these factors:

$$\Delta T = Q \frac{S}{K} \qquad \textbf{(1)}$$

The characteristic 63% response time for a Micro-Foil® sensor is approximated by:

$$\tau = \frac{4(XS)^2 \rho C_p}{\pi^2 K} \qquad \textbf{(2)}$$

t = response time
r = density
C_p = specific heat
K = thermal conductivity
X = cover layer factor
1.2 (thick **S**) to 2 (thin **S**)

Thin sensors provide both fast response and straight-thru heat flow.

Thermal Applications

Regardless of application, the primary function of the heat flow sensor is to obtain, as accurately as possible, a direct indication of the thermal energy transfer per unit time per unit area. In the majority of the cases, this is expressed in units of Btu–ft–-2-h–1. In all instances, the heat flow measured will be the thermal energy resulting from conductive heat transfer, or combinations of the following heat transfer modes. Therefore, a discussion of each mode of heat transfer follows:

Conductive Heat Transfer

For measurement of conductive heat transfer, whether it be in insulating materials, existing structures or in complex laminated materials, the main consideration is that introduction of the heat flow sensor must have negligible effects on the process of heat conduction. The best method for insuring intimate contact of the sensor with the test structure is: if it can be, in effect, cast within the material.

Obviously, this results in a permanent installation and offers the best results. There will be many cases when the integral installation technique is not possible. In these cases, the sensor may be bonded to the inner or outer surface of the material or structure being tested. This measurement technique is based on the fact that the thermal energy conducted through the material must also pass through the sensor before being dissipated into the surrounding environment.

Convective Heat Transfer

Convective heat transfer is often closely associated with conductive heat transfer, since thermal energy conducted through enclosure walls may be transferred throughout the enclosed volume by convection. Installation criteria for convective applications are therefore analogous to those of conductive applications where the sensor is attached to the inner or outer surfaces of the walls or structural materials. One exception, although rarely occurring in everyday testing, is that in high velocity flow regions, the existing airflow may be laminar in nature. Attachment of a sensor directly on a surface in laminar flow may result in disturbances of the flow, culminating in turbulent airflow; precautions should be taken to avoid this. The usual technique is to recess the sensor an amount equal to its thickness, thus making the installation flush with the surrounding area.
It should be emphasized that it is a rare case where high velocity airflow is found with regard to day–to–day testing. Cases where this is a very important consideration are in applications such as the aerospace industry for airborne testing, wind tunnel testing, etc.

Radiant heat transfer

Measurement of absorbed radiant energy has only one prime requisite, which is: the sensor must have the same absorption or reflection qualities as the surface under test. One fortunate factor in general testing is that since there is no perfect reflector or perfect absorber, most materials other than clean, smooth metals fall in an emissivity or absorptivity range of 0.4 to 0.8. Typical Micro-Foil® heat flow sensors have a nominal emissivity of 0.7. The standard sensor is a good match for a large number of materials.

For more critical applications such as may be encountered when selecting coatings for walls, siding, etc., the sensor may be coated with the same material that the structure is coated with after bonding to the surface and thereby providing an identical emissivity and absorptivity as the area under test.

Best results are obtained with a black coating over everything because high absorptivity is the most reproducible and stable. A permanent black surface is a new option on RdF Micro-Foil® heat flow sensors.

Mounting Considerations

For accurate measurements, the chosen mounting method needs to provide a bond line free of visible voids. Thin bonds maximize response. Continuous thin bonds are achieved by any of the following methods.

The ease of installation of the Micro-Foil® sensors makes their applications almost unlimited. The thin and flexible sensors can be attached to flat or curved surfaces and may be permanently bonded in place with conventional adhesives or epoxies. A convenient method for continued re-use at numerous locations is their installation using double adhesive-backed mylar tape. Upon installation, simply connect the leads to a millivoltmeter or similar readout device and a direct measurement of the surface heating or cooling rate in technique is based on the fact that the thermal energy conducted through Btu–ft–-2 -h–1 or equivalent units is provided.

For a single use temporary installation, Micro-Foil®heat flow sensors may be ordered with optional pressure sensitive adhesive (PSI) on the mounting surface. The adhesive layer is protected with a release sheet which is removed for use.

There are other cases where heat flow data is required over a long or extended period. The best method of insuring stable installation for the entire period is to provide a permanent installation. Each user may have his own preference as to an adhesive for mounting the sensor. A few recommendations which have been found satisfactory for past applications are as follows: for attachment to very smooth surfaces much as metallic, plastic or glass surfaces, cements such as Eastman No. 910 have been very satisfactory. For roughened surfaces such as walls, liquid epoxy, or a fast setting RTV are useable to temperatures as high as 250°F. This type of epoxy also has the advantage of curing at room temperature. For the few instances where a high temperature epoxy is desired, Emerson-Cuming No. 104 is useable to in excess of 450°F. However, the use of this adhesive requires an elevated temperature cure such as in an oven or use of radiant heat lamps

Instrumentation

Since Micro-Foil® heat flow sensors are self- generating devices that yield an output signal in millivolts or microvolts (depending on sensitivity and range), commonly available readout instrumentation, that can resolve these signals, is all that is required by the user.

Temperature should be determined at the time the heat flow measurement is made. Apply the available temperature correction to readings at temperatures below freezing. The correction for warm temperatures <110�F can normally be neglected. See Figure 4. In many applications, foil type or fine-wire thermocouples built directly into a Micro-Foil® heat flow sensor provide accurate temperature measurement at the best location. A heat flow measurement installation, shown in Figure 2, illustrates possible specialized display instrumentation that today is provided by instrumentation system logic functions.

Calibration, Specifications & Accuracy

The primary calibration function of heat flow sensors is performed using an adiabatic calorimeter. The calibration sensor is carefully mounted on a copper calorimeter slug and a flat black coating is applied to all sensor surfaces for uniform absorptance. The calorimeter slug is then exposed to a radiant heat source on one surface at various power levels. A schematic of radiant heat flux facility is shown in Figure 3.
For production calibration, a comparison calibration setup is used whereby a test sensor is compared in heat flow series conduction with a primary standard sensor that has been radiation calibrated as described above. The production calibration is performed at 70°F and temperature correction data is provided over the operating temperature range. A typical temperature correction chart for Micro-Foil® heat flow sensors with a Kapton® thermal barrier is shown in Figure 4.

Both radiation and conduction were used in the methods of calibrations described above. A recent NIST study has confirmed that the results apply accurately in convection heat flow as well. RdF's thin sensor results in the reference (see next page) were much better than results on thick sensors by others.

Because of their extremely thin construction, Micro-Foil® sensors feature true isothermal properties where thermal losses are kept to a minimum and highly accurate readings are obtainable. The sensors provide self-generated millivolt or microvolt outputs, which are proportional to the heat flow through the sensor thickness. Catalog choices of sensitivity are offered by changing the thickness of the thermal barrier and/or the number of thermopile junctions within the sensor.

Typical specifications are as follows:

Heat flow range: Up to 30,000 Btu–ft–-2-h–1.
For heat flow above 3000 Btu–ft–-2-h–1 The installation must prevent overheat. (New water cooled model 27650 is a laboratory grade instrument continuously useable to over 100,000 Btu–ft–-2-h–1 with 2x overrange capability, fast 0.02 second response time and a permanently black sensing surface.)

Typical sensitivity: 0.07 to 40 MV-Btu–ft–-2-sec–1

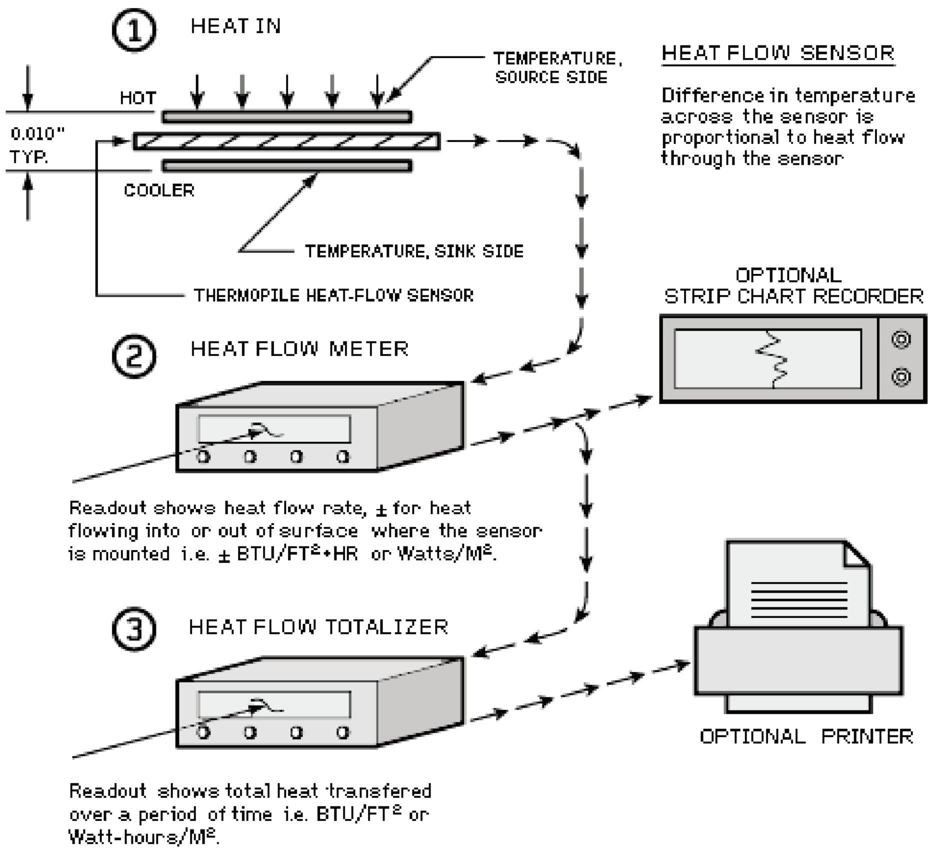
Typical response time: 0.02 to 0.50 secs. (function of matrix material thickness)

Typical thermal impedance: 0.003 to 0.015 Btu–ft -h (determined by properties of matrix material and thickness)

Typical thermal capacitance: 0.01 to 0.05 Btu–ft–-2-°F–1

The use of the calibration procedures described provides sensors with a typical absolute calibration accuracy of 3 to 5%. Reproducibility is in the order of 1%. The construction of the sensor provides infinite resolution over the heat flow range.

Figure 2. Heat Flow Measurement Installation and How It Works.



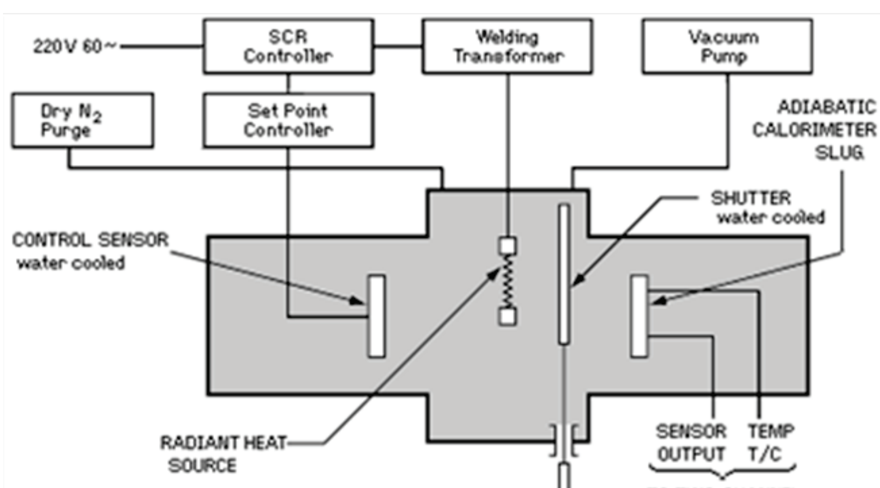


Figure 3. Radiant Heat Flux Facility

- 3 -

Specialists in Temperature Measurement

AS9100 ISO 9001 CERTIFIED COMPANY

Summary

Micro-Foil® heat flow sensors are simple devices that can be used to measure heat flow in discrete locations. The sensors are unique because they are very thin and flexible to conform on flat or curved surfaces and provide minimal thermal perturbations to the heat flow. Installation is easy using conventional adhesives or joint filler to establish thermal coupling for good accuracy. They require no special wiring, reference junctions, or special signal conditioning. Applications for this unconventional measurement are continuously expanding along with the ability of control systems to utilize the performance information provided.

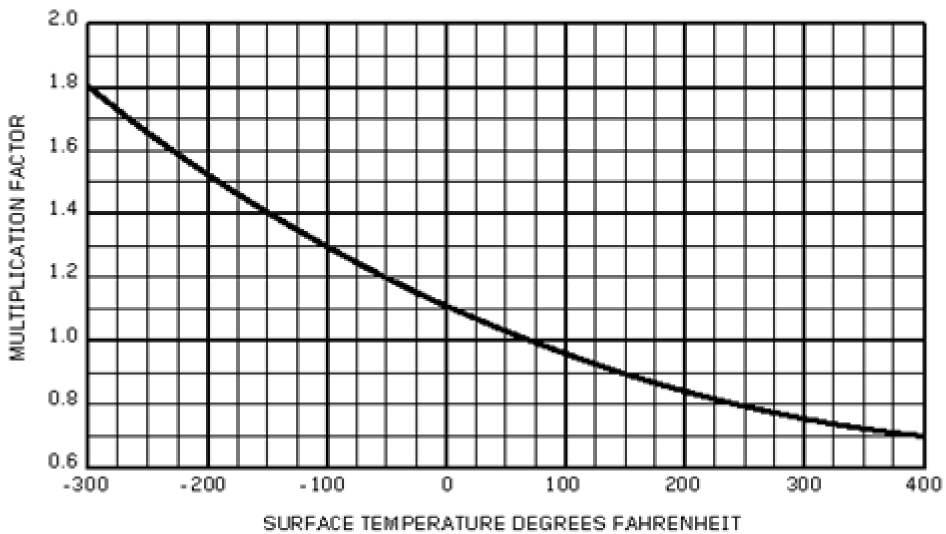


Figure 4. Output Multiplication Factor vs. Receiving Surface Temperature
Micro-Foil® Heat Flow Sensor (70°F Base)

Reference:

Holmberg, D. G., Womeldorf, C. A., 1999, “Performance and Modeling of Heat Flux Sensors in Different Environments” HTD-Vol. 364-4, Proceedings of the ASME Heat Transfer Division - 1999 Vol. 4, pp. 71-77.

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Appendix C: TEST 3 – Testing Layering Configurations

Appendix C provides details regarding when comparing differing layers configurations. Also, details for sensors proposed to be used for future work have been included.

C.1 Tank-top Portable Radiant Heater

A single tank-top radiant heater attached to a propane tank was used as a heating source for all of TEST 3. This system fits on a standard 20 lb. LP cylinder and provides a variable output. The heat output was to the maximum output (i.e. 13 kW) for testing of both Arrangement A and B.

Figure C1: Tank-top Portable Radiant Heater

C.2 IR Camera

The IR camera was used to capture testing for both Arrangements A and B during TEST 3. These files are available in the attached memory stick and organized using the following directories: D:\DRDC_TEST3_T_17C and D:\DRDC_TEST3_T_-20C. Each of these directories contains three .WMV files: one at normal speed, another at 4 times faster than normal (i.e. file name includes 4x timelapse) and the last 16 times faster than normal (i.e. file name includes 16x timelapse) to facilitate file viewing.

Also, please note that the IR camera recalibrates the temperature scale (shown on the right hand side of the screen) each time the screen shows the “Saving File” message.

C.3 Next Steps

Introduction

The Operative Temperature Transducer enables you to evaluate the effect that objects/surfaces of varying temperatures have on the body.

Normally, the amount of heat given off by a human body through radiation is approximately the same as the amount of heat given off by convection. Therefore, a simple air temperature measurement is a bad indication of the thermal environment. Operative temperature takes both radiation and convection into account and is therefore a much better indicator. Many of the standards used today recommend measuring the operative temperature.

Operative temperature (˚C) is defined as the uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation and convention as in an actual non-uniform environment.

The transducer is designed for use with INNOVA instruments: 1221, 1303 and 1309.

Transducer Design

Four major factors were taken into consideration during the design of this transducer:

Size
The size has been chosen so that the ratio between heat loss by radiation and by convection is similar to that of the human body.

The human body has an effective radiation area of only 0.7 times its surface area (due the insides of the arms and legs radiating against the body). If the transducer had the same surface area as the human body, its simple shape would lose 1.4 times more heat by radiation than a human body.

However, the convection heat loss per unit surface area increases as the size of an object is reduced. By reducing the size of the transducer, the mean radiant temperature and air temperature have the same weighted influence on the transducer as on a person.

Shape
The shape of the transducer is determined by the need to obtain the same angle factor to the individual room enclosures as for a human being. This has been achieved by using an ellipsoid shape.

Color
The transducer’s Color and emission coefficient have been chosen so that

the long- wave radiation absorbed by the transducer is the same as that of both a naked and a dressed person. It is not possible to simulate people in both dark and light colored clothing for short-wave radiation. The grey Color chosen simulates both naked people and people dressed in light colored clothing.

Orientation

People do not maintain the same posture. For this reason, the transducer has three settings: vertical, 30˚ from the vertical, and horizontal, which represent the body in the standing, sitting and lying positions respectively.

Uses:

- Measures Operative Temperature
- Provides input for thermal comfort evaluations

Features:

- Complies with ISO7726
- Same ratio between heat loss via convection and radiation as the human body
- Same angle factor to its surroundings as the human body
- Absorbs the same proportion of long- and short- wave radiation as the human body
- Handy size

Cable Connections

The integral cable supplied with the transducer is fitted with a standard 4- pin DIN plug. When the transducer is used with a Thermal Comfort Data Logger, it is normally plugged into the Temperature socket, but it can in fact be used in any socket designed to receive temperature information. Electrically, the transducer is equivalent to a Pt100 resistor in a four-wire configuration. This means that extension cables can be used without a loss of accuracy.

Evaluation of Thermal Comfort

The temperature value from this transducer (to) enables you to evaluate the thermal comfort and calculate PMV values according to ISO7730. PMV values are calculated using humidity, air velocity, *Clo*. and *Met*. rates without having to measure the mean radiant temperature (*tr*) (which is often a difficult parameter to obtain).

Evaluation of Heat Loss

When you evaluate the energy consumption of a building, you must measure the temperature difference between the indoor and outdoor environments. The operative temperature is commonly used to provide the indoor temperature.

SPECIFICATIONS:

Measurement Range and Accuracy:
5 to 40˚C range ±0.3˚C
(41 to 104˚F range ±0.5˚F)
-20 to 50˚C range ±0.5˚C
(-4 to 122˚F range ±0.9˚F)

Electrical Output:
A Pt100 signal in a 4-wire connection

Response Time:
1 min. to 50% of step change, 10min. to 90% in still air

Integral Connection Cable:
Length 3m; connected to associated equipment via a 4-pin DIN plug

WEIGHT:
230g (8oz.)

DIMENSIONS:
Length:
160mm (6.3in) excluding handle
Diameter: 54mm (2.1in)

CE	**COMPLIANCE WITH STANDARDS** CE-mark indicates compliance with EMC Directive and Low Voltage Directive.
Safety	EN 61010-1 (1993) & IEC 1010-1 (1990): Safety requirements for electrical equipment for measurement, control and laboratory use.
EMC Emission	EN 50081-1 (1992) : Generic emission standard. Part 1: Residential, commercial and light industry. EN 50081-2 (1993): Generic emission standard. Part 2: Industrial environment. CISPR 22 (1993): Limits and methods of radio disturbance characteristics of information technology equipment. Class B Limits. FCC Class B limits.
EMC Immunity	EN 50082-1 (1992): Generic immunity standard. Part 1: Residential, commercial and light industry. EN 50082-2 (1995): Generic immunity standard. Part 2: Industrial environment. **Note:** The above is guaranteed using accessories listed in this Product Data sheet only.
Temperature	IEC 68-2-1 & IEC 68-2-2: Environmental Testing. Cold and Dry Heat. Operating Temperature: -20 to +50°C (-4 to 122°F) Storage Temperature: -25 to +70°C (-13 to 158°F)
Humidity	IEC 68-2-3: 90% RH (non-condensing at 40°C).
Mechanical	IEC 68-2-6: Vibration: 0.3 mm, 20m/s², 10-500 Hz. IEC 68-2-27: Shock: 1000 m/s². IEC 68-2-29: Bump: 1000 bumps at 250m/s².

Ordering Information

MM0060 Operative Temperature Transducer

Optional Accessories

1221	Thermal Comfort Data Logger
1303	Multipoint Sampler and Doser
1309	Multipoint Sampler
DH0492	Tripod Mounting Adaptor for 3 Transducers
UA1347	Tripod Mounting Adaptor for 4 Transducers
KE0357	Transducer Carrying Case
UA0803	Tripod
UA1348	Tripod Extension Rods (3)
UA0588	Transducer Mounting Adaptor
WL0690	Extension Cable
WL0690/y	Extension Cable (definable length up to 100m; y is length in meters)

LumaSense Technologies reserves the right to change specifications and accessories without notice.

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