UNIVERSITY OF CAMBRIDGE
Department of Engineering

Interim Report on the Energy Appraisal of Retail Units:

Assessing the effect of open doors on energy consumption and thermal comfort

Technical Report Number: CUED/D-STRUCT/TR232

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Chapter 1

Introduction

1.1 Introduction

Reducing energy consumption to mitigate climate change is becoming an increasingly key issue in all range of sectors. To help tackle this important issue the UK government under the Climate Change Act aims to reduce CO_2 emissions to 34% below 1990 levels by 2020. This target can only be achieved if each sector takes on the responsibility to reduce their carbon footprint.

Department of Energy and Climate Change states that in 2008 the service sector accounted for 19 % of final energy consumption in the UK, within this sector; retail comprised of 20% of the total used energy. [1] Figure 1.1 displays the breakdown of energy usage within the retail sector in 2008.[2]

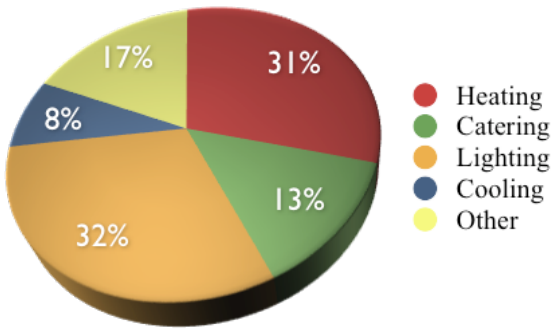

Figure 1.1 Energy Use in the Retail Environment

As can be seen from Figure 1.1, the retail industry uses 31% of its energy for heating purposes. However, a portion of this energy will be lost to the external environment through the building fabric (i.e. heat loss), which is exacerbated by poor practices such as leaving the external doors open. To compensate for this heat loss, retailers increase their heating use or instal air curtains above doors that raise operating costs and increase their carbon footprint.

1.2 Objective

This research project aims to quantify the reduction in annual energy consumption and CO_2 emissions of the retail stores when external doors are kept shut, thereby raising the awareness of wasteful practices. Collaboration between the Close the Door Campaign and Glass & Façade Technology Group at University of Cambridge has instigated a comprehensive study addressing this specific issue. In this project the real-world performance of the retail outlets was monitored during the heating season. The published results seek to enable retail building owners and local authorities to determine the benefits of this energy saving measure. The findings aim to encourage retailers to take positive steps for both economic and environmental reasons while enhancing their corporate reputation.

[1] DECC (2010) Energy Consumption in the UK Overall Data Tables – 2010 Update
[2] DECC (2010) Energy Consumption in the UK Service Data Tables – 2010 Update

Chapter 2

Methodology

2.1 Introduction

This chapter describes the characteristics of the stores, experimental setup and the equipment used in the monitoring study.

2.2 Stores

The retail sector consists of a wide range of stores, differing in size, orientation and door configuration. These factors account for various energy demand levels due to differences in heating/cooling requirements and microclimate effects such as building fabric losses and infiltration. To investigate the possible effects of these factors on energy and thermal comfort, two stores that were different in typology were chosen for the study.

The two stores chosen for the monitoring study were the Ryman Stationary and the Cambridge Toy Shop both located in Cambridge, UK. The location and the orientation of the store entrances can be seen in Figure 2.1. The Cambridge Toy Shop, which faces southeast, is situated on a sheltered pedestrian passage. Ryman Stationary, facing northeast, is located on a wider street and a more exposed location.

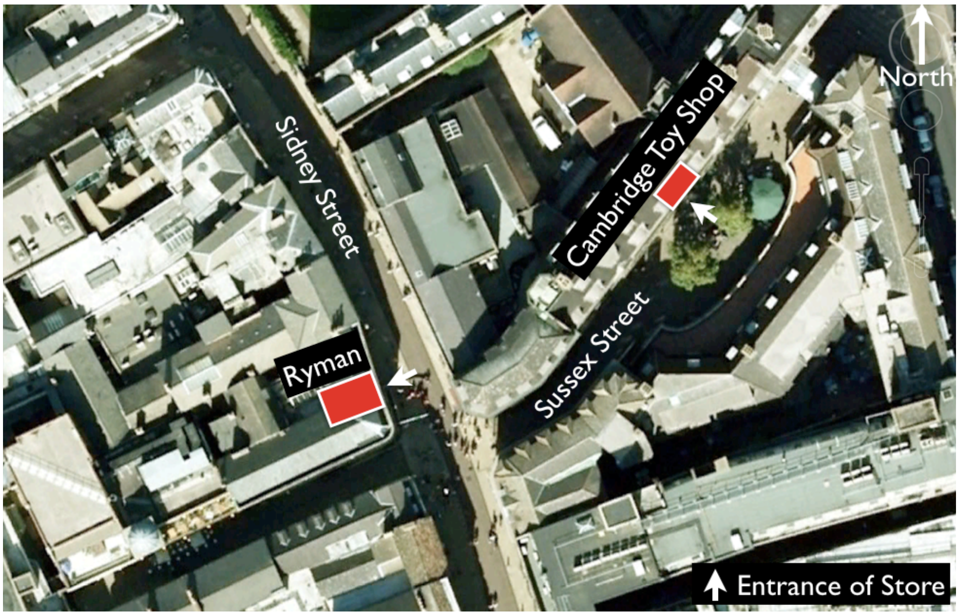

Figure 2.1 Location of the Monitored Stores

In addition to the location and orientation of the individual stores, the layout and door configuration of the shops differed as described in Section 2.2.1 and Section 2.2.2.

2.2.1 Cambridge Toy Shop

The Cambridge Toy Shop is an independent store located on Sussex Street. Figure 2.2 shows the front of the store, which consists of a single glazed display in a timber frame spanning a total width of 9.13 m. The entrance to the store is through a single door opening, measuring 0.9 m, which is recessed to minimize infiltration. The floor-to-ceiling height of the shop floor on the ground floor is 3.25 m. There exists stairs that lead to the downstairs shop floor at basement level, which has a height of 2.5 m.

Figure 2.2 Front View of the Cambridge Toy Shop

Figure 2.3 shows the ground floor plan of the Cambridge Toy Shop. The total floor area of the store is 158 m^2. The width to depth ratio of the Cambridge Toy Shop is 1:1.1.

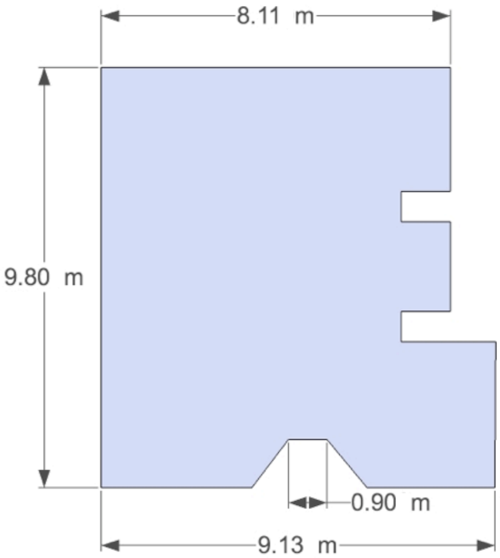

Figure 2.3 Ground Floor Plan of Cambridge Toy Shop

2.2.2 Ryman Stationary

The Ryman Stationary, which is part of a privately owned chain store, is located on Sidney Street. Figure 2.4 shows the single glazed display supported by an aluminium frame spanning 8.15 m, which includes the width of the doors. Access to the shop is through the two double doors, however one of the four doors is permanently kept shut which results in a total entrance width of 2.7 m. There exists a basement isolated from the ground floor by a door, which is kept closed.

Figure 2.4 Front View of Ryman Stationary

Figure 2.5 shows the floor plan of Ryman Stationary, the floor area of the shop floor is 153 m^2 and the height is 2.6 m. The depth of the store is 21.85 m, making the width to depth aspect ratio 1:2.7.

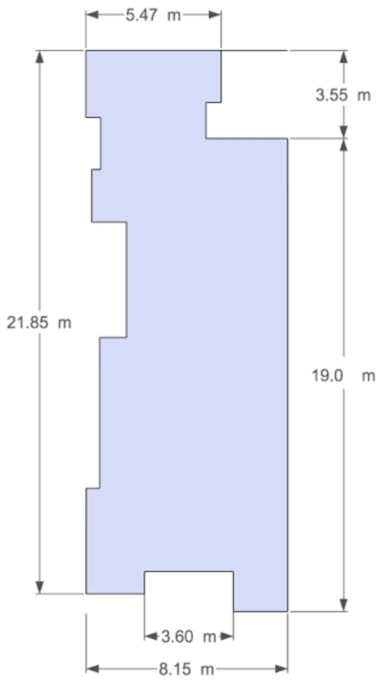

Figure 2.5 Ground Floor Plan of Ryman Stationary

2.3 Equipment

The key parameters that were the focus of the investigation were, energy consumption thermal comfort, customer footfall. To monitor these parameters the necessary toolkit consisting of sensors had to be installed into the stores.

The following factors were crucial while acquiring the required set of sensors. The sensors should:

i. Cause no interference to the operation of the store
ii. Be easily deployed and removed
iii. Provide highest achievable accuracy given cost limitations
iv. Have logging capacity sufficient for the required time frame
iv. Allow data captured to be easily gathered and structured

2.3.1 Energy Demand Monitoring

A wireless energy monitoring system was installed at each store consisting of three power meters and a hub. Figure 2.6 displays the power meters attached to each phase of the three-phase power supply at the Cambridge Toy Shop.

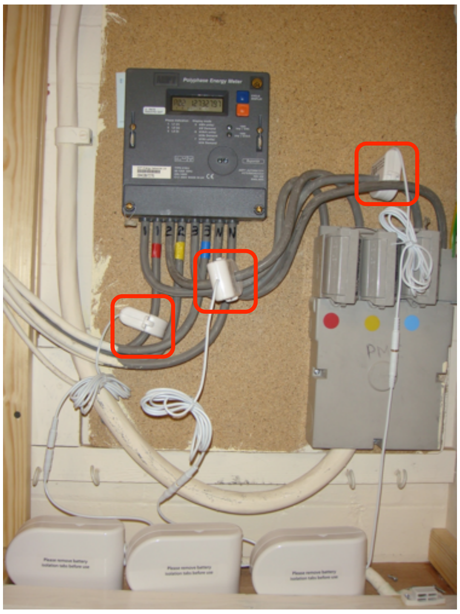

Figure 2.6 Power Meters on the three-phase Supply

To measure the energy demand there is a need to measure voltage, current and power factor however most power meters measure current because both voltage and power factor are likely to be stable. The clamps attached to the power cables shown in the red square measure the current and relay this information onto the hub.

Smartplugs were also used to measure the energy consumption of individual appliances. Figure 2.7 outlines the components of the system and the communication between the components.

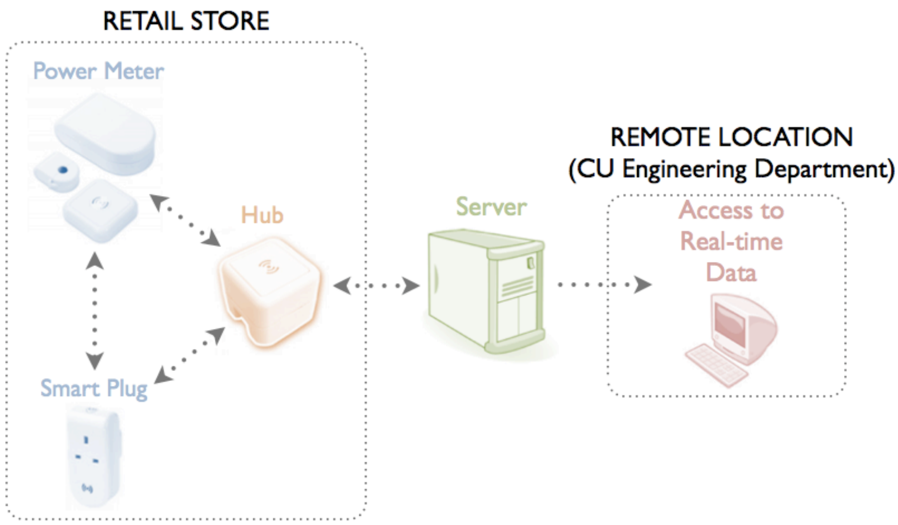

Figure 2.7 Schematic of the Energy Monitoring System

The power meters and smartplugs communicate on a ZigBee wireless network which works on a mesh based system. This type of network has high reliability and increased range due to the ability for each sensor to communicate with each other and the hub. This network is very low powered and has a low data rate allowing the small batteries in the sensors to have long life. Each individual sensor measures and wirelessly transmits the measured data at pre-determined intervals to the hub. The hub is connected to broadband internet allowing it to instantaneously relay the received data to a remote server. The information communicated to the server is stored electronically and made available for online access, allowing energy demand at one-minute intervals to be retrieved and analyzed.

2.3.2 Internal and External Environment Monitoring

The internal temperatures inside the stores were measured using temperature & humidity sensors. The placement of these sensors inside the store required them to be small, durable and out of reach from children. Figure 2.8 shows the type of sensor that was chosen for the study.

Diameter: 1.17 cm

Height: 0.6 cm

Figure 2.8 Temperature and Humidity Sensor

They were located at 1.5 m above the floor at suitable locations throughout the store; the locations of these sensors were limited by the availability of shelves. The accuracy of the sensors was ± 0.5 ^{o}C for temperature and ±5% for humidity. The internal 8KB of data logging memory allowed logging capacity up to one week at five minute intervals. This stored data was transferred onto a computer using a data cable.

The external conditions were captured using a weather station. Figure 2.9 shows the external unit.

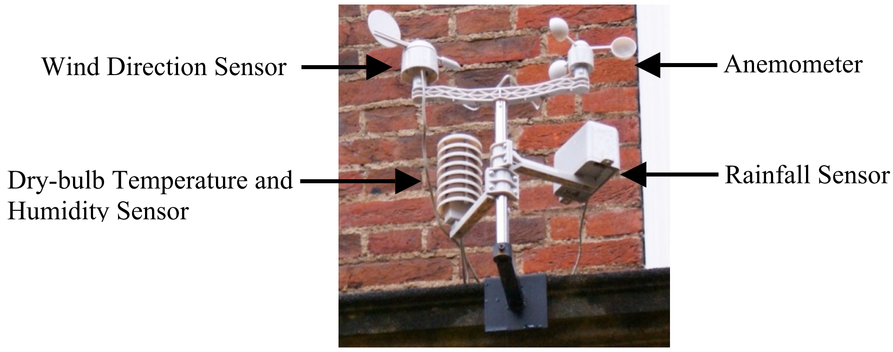

Figure 2.9 Weather Station above the Cambridge Toy Shop

The weather stations were placed above the stores at suitable locations as close as possible to the front doors of the stores. They comprise of the external sensors to measure outside temperature, relative humidity, wind speed, wind direction, atmospheric pressure and rainfall. Communication between indoor and outdoor unit is established through 868 MHz radio frequency. The accuracy of the temperature sensors for the indoor and outdoor units was ± 1 ^{o}C for temperature, ±5% for humidity and ±1 m/s for the wind velocity.

2.3.3 Customer Footfall Monitoring

The customer footfall was measured using a door activity sensor for days when the doors were closed. This sensor shown in Figure 2.10, consists of two components. A magnet is attached to the door and the component attached to the doorframe, which works on a magnetic switch mechanism, sends a signal to the hub each time the door is opened. Working on the same network as described in Section 2.3.1, data on the number of times the door has been opened is accessed online.

Figure 2.10 Door Activity Sensor

During open door days, the customer footfall was measured using a small transmitter and receiver that are placed on either side of the entrance shown in Figure 2.11.

Figure 2.11 People Counter Installation at the Cambridge Toy Shop

These units have an internal battery and have low battery consumption. Each time a customer walks in or out of the store, the infrared beam signal between the units is interrupted. The transmitter counts the number of incidences this occurs; this is manually read on the display of the transmitter unit at the end of business hours.

2.4 Methodology

The monitoring study was conducted simultaneously in both stores during winter, between 25th February 2010 and 16th March 2010. To identify the difference in energy consumption and thermal comfort between different door configurations, two cases were investigated during winter:

	Door Status	**Air Curtain**	**Set Point Temperature**
Winter	Open	ON	19-21 °C
	Closed	OFF	

Table 2.1 Description of Open and Closed Door Cases Investigated

Heating: Both stores were using two A/C units to heat the stores. The heating was turned ON at the start of business hours. The units were used to achieve the required internal temperatures, which were 19-21 °C for winter. This temperature range is the recommended temperature range for retail buildings operating during winter, as published by Chartered Building Services Engineers.[3] The point in time that the lower or upper set point was reached was indicated by an audible alarm from the indoor controller of the weather station, at which the staff turned ON/OFF the units. The settings for the heating were kept constant throughout the study. The requirement for such a process to control the operation of the A/C was due to the lack of a thermostat in Ryman Stationary and the inaccuracy of the thermostat in the Cambridge Toy Shop.

[3] CIBSE, Guide A: Environmental Design. London: Chartered Institution of Building Services Engineers

Air Curtain Operation: The Cambridge Toy Shop had a single air curtain whereas the Ryman Stationary had three air curtains operating during winter open door days. They were switched on during start of business hours and remained operational until store closing.

Chapter 3

Results and Discussion

3.1 Introduction

This chapter presents the findings gathered from the monitoring of the retail units. The experimental results on the energy performance and the thermal conditions will be shown for individual stores. From the findings a method to estimate the annual savings during the heating season will also be presented.

3.2 Energy Performance of the Cambridge Toy Shop during the Heating Season

3.2.1 Energy Consumption and Effect of External Conditions

The monitoring study conducted during the heating season for the Cambridge Toy Shop was carried out between 27th February 2010 and 16th March 2010. Figure 3.1 below displays the total energy consumed during business hours.

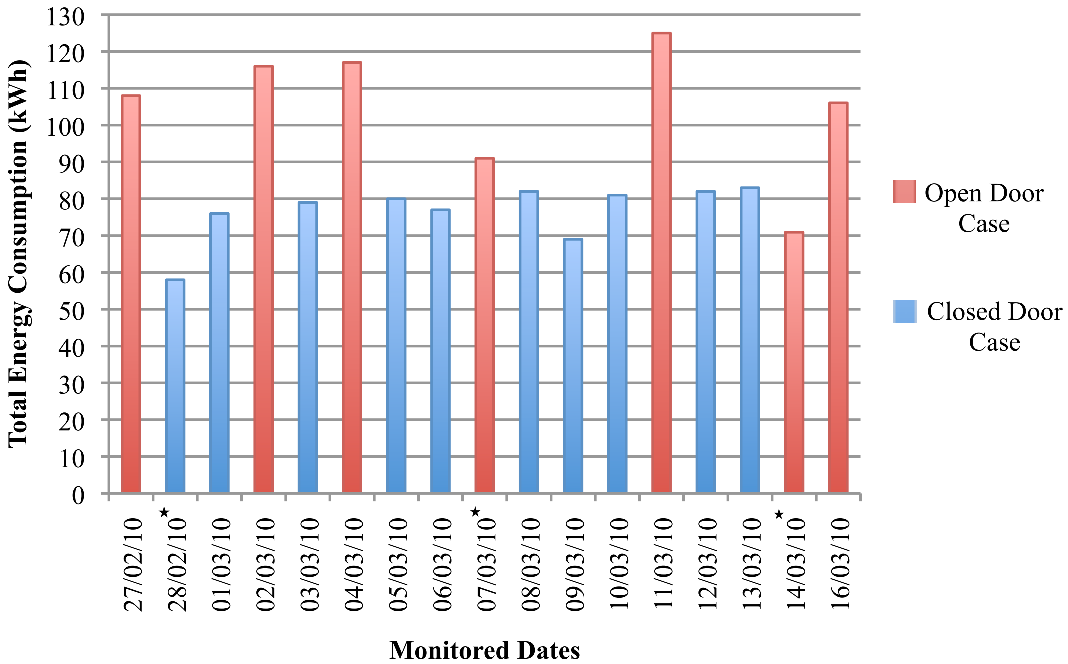

Figure 3.1 Monitored Energy Consumption for Cambridge Toy Shop during Heating Season

Figure 3.1 shows that when the doors are left open on a given day the mean energy consumption of the store is significantly increased. This increase in energy is due to the operation of the air curtain and the additional length of time that the heating equipment is used.

The lower energy consumption observed on days marked with a star is the result of the shorter operating hours. Moreover, the low energy consumption observed on March 9th is due to instructions given to the staff to operate the store as they would normally over the winter. Whereby, the outside door is shut and that no heating is used.

There are differences in energy consumption between days with the same door configuration. Table 3.1 displays the calculated energy differences, showing the average and the standard deviation between the different cases.

Table 3.1 Mean Energy Consumption of Closed and Open Door Cases for Cambridge Toy Shop during the Heating Season

	Mean Energy Consumption for Closed Door Cases (kWh)	**Standard Deviation for Closed Door Cases (kWh)**	**Mean Energy Consumption for Open Door Cases (kWh)**	**Standard Deviation for Open Door Cases (kWh)**
Weekdays & Saturdays	80	2.5	114	7.6
Sundays	58	N/A	81	N/A

The difference between mean energy consumption for weekdays and Saturdays is 34 kWh, whereas for Sundays it is 23 kWh. The standard deviation between the open door cases is 7.6 kWh; whereas the closed door cases it is 2.5 kWh. This difference in standard deviation was further investigated by examining the possible effect of wind speed and external temperatures.

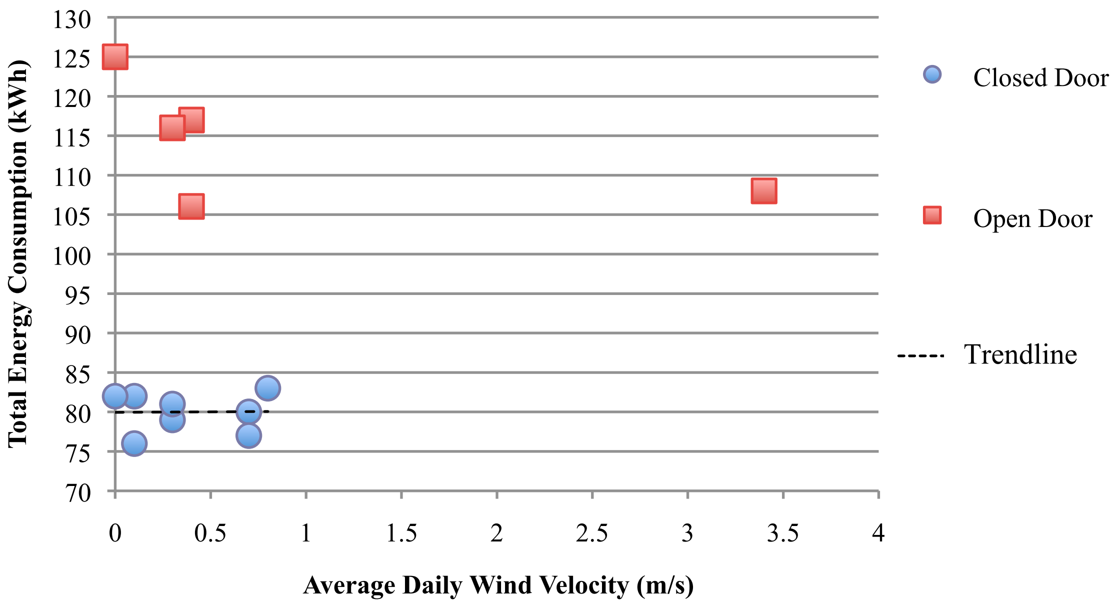

Figure 3.2 Effect of Wind Velocity on Total Energy Consumption during Heating Season for the Cambridge Toy Shop

Figure 3.2 indicates that the wind velocity does not effect the energy consumption when doors are closed, however due to the number of data points a trend can't be established for the open door cases.

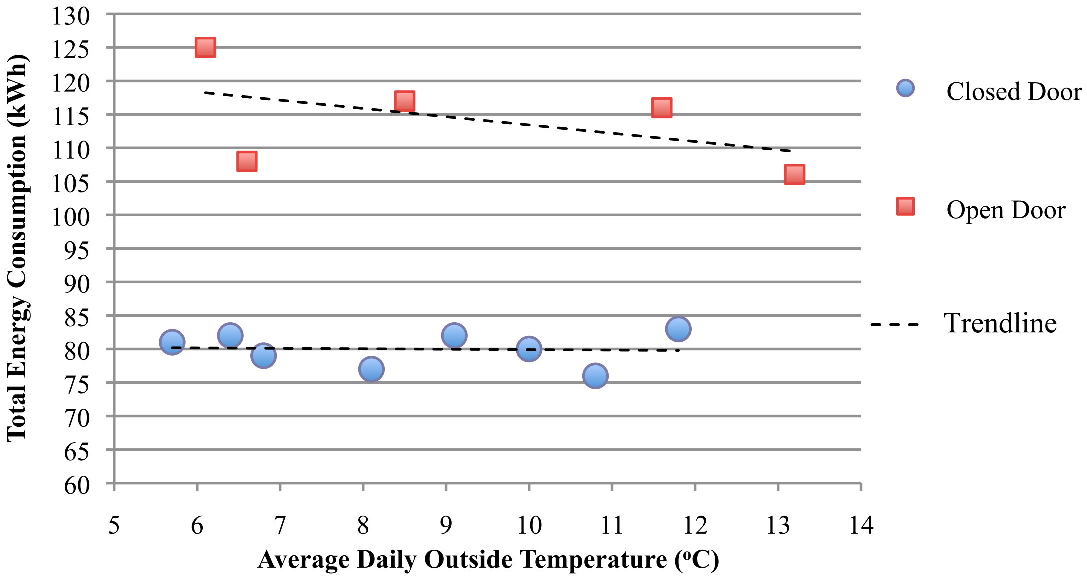

Figure 3.3 Effect of Outside Temperature on Total Energy Consumption during Heating Season for the Cambridge Toy Shop

Figure 3.3 demonstrates when doors are closed the outside temperature has negligible effect on the energy consumption however for open door cases higher outside temperatures result in lower total energy consumption.

3.2.2 Energy Demand Profiles for Different Door Configurations

The energy profile data obtained from the power meters allow further investigation of the differences in energy consumption between the different door configurations. Days with comparable external conditions were selected for comparison; the external conditions for the chosen days are summarized in Table 3.2.

Table 3.2 Comparison of External Conditions for the Closed and Open Door Cases for Cambridge Toy Shop

	March 8, 2010	**March 11, 2010**
Door Status	Closed	Open
Average Outside Temperature (°C)	6.4	6.1
Daily Minimum (°C)	1.8	3.5
Daily Maximum (°C)	10.5	7.2
Average Wind Speed (m/s)	0.1	0

Figure 3.4 is the plot of the energy profile gathered from power meter data. From store opening to 12:48 is a time period when the heating equipment and lighting are operating which is a load on average of 12.4 kW. The fluctuating energy profile during this period is due to the cyclic operation of the heating equipment.

Once the upper temperature set point is reached at 12:48, the heating is turned off and the only load remaining is lighting which consumes 8.8 kW.

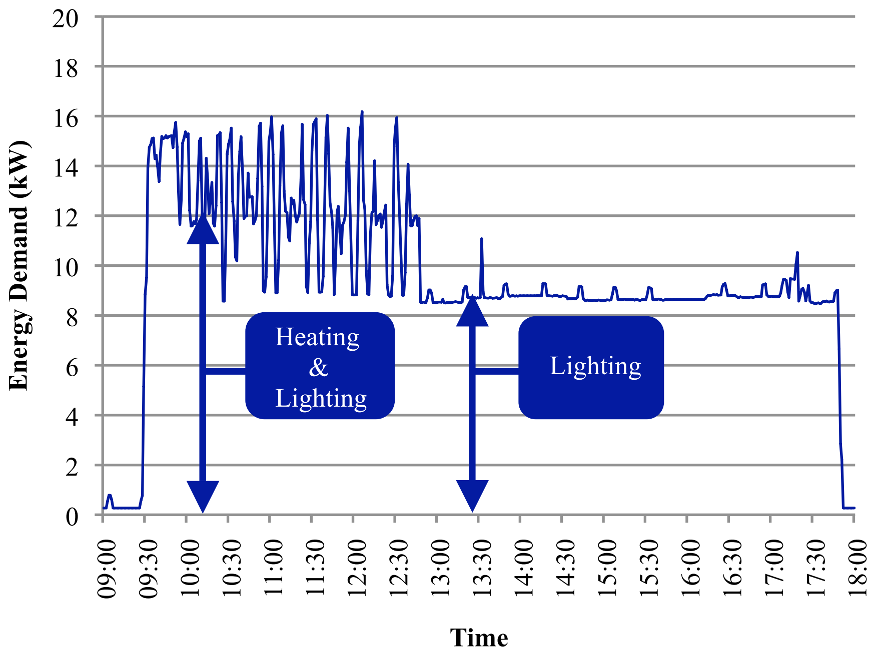

Figure 3.4 Energy Consumption Profile for March 8, 2010 (Closed Door Case)

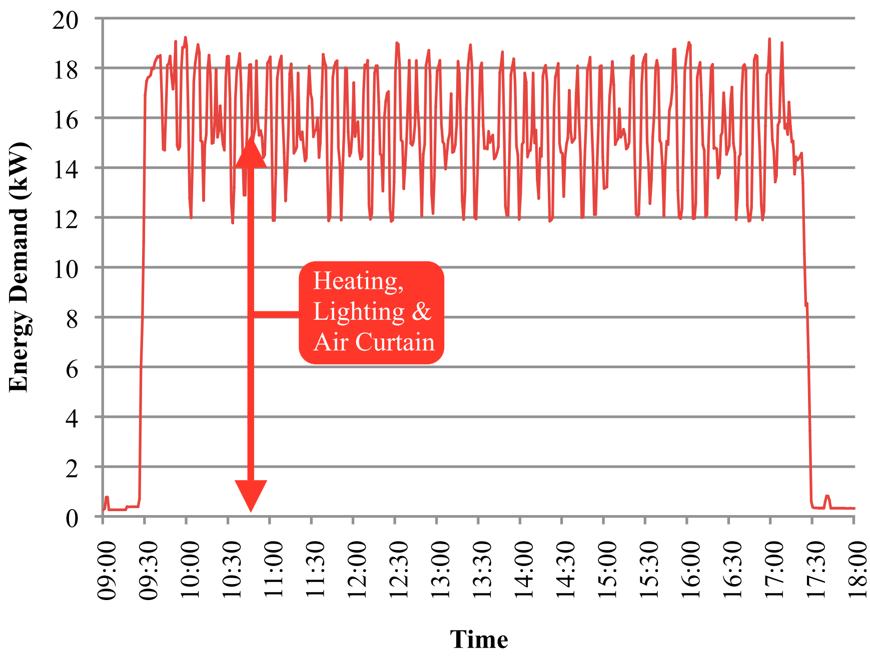

Figure 3.5 Energy Consumption Profile for March 11, 2010 (Open Door Case)

Figure 3.5 represents the energy profile during March 11, 2010. The load throughout the day is on average 15.6; it is comprised of the heating, lighting and air curtain. Unlike the closed door case there is no step-change in power demand. When the doors were open the set-point was never reached hence the continued operation of the heating equipment throughout the whole day.

Figure 3.6 displays the total energy breakdown for the compared days. The total energy consumption for March 8, 2010 is 82 kWh whereas for March 11, 2010 it is 125 kWh.

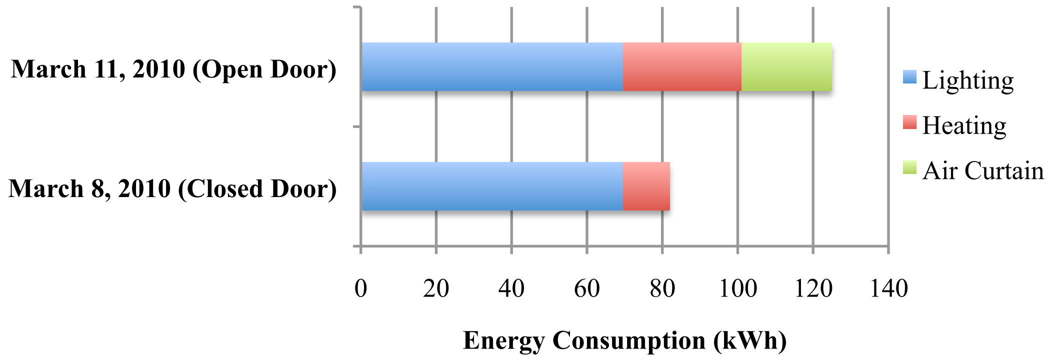

Figure 3.6 Breakdown of Energy Consumption

The energy difference of 43 kWh is comprised of the operation of the air curtain for eight hours consuming 24 kWh and the additional five hours of usage of the heating equipment totaling 19kWh.

The data gathered from the power meters indicated the various loads; the heating load is 3.6 kW when both A/C units are running on the manual set heating controls. The air curtain consumes 3 kW and the largest contribution to energy consumption is due to the lighting, which consumes 8.8 kW.

The difference in energy consumption corresponds to an energy saving of 34.4 % between the compared days.

3.3 Investigation of Internal Conditions of the Cambridge Toy Shop during the Heating Season

3.3.1 Thermal Comfort Levels

In this section the thermal comfort, considering temperature and relative humidity levels on the ground floor of the Cambridge Toy Shop will be investigated. The purpose of this study is to determine the areas of the store where thermal comfort problems may arise. The days investigated for energy performance, March 8th and March 11th were also chosen for the comparison of internal temperatures. The similar external conditions will minimize the differences in internal conditions due to heat losses through the glazing and walls. Figure 3.7 outlines the locations of the temperature & humidity sensors.

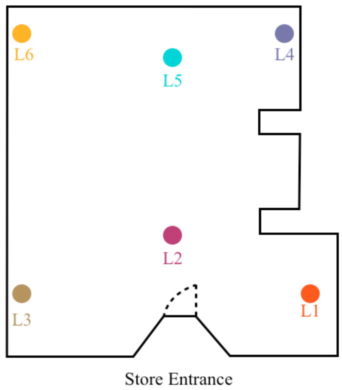

Figure 3.7 Locations of the Temperature Sensors in the Cambridge Toy Shop

Figure 3.8 displays the measured temperature at each individual location on March 8, 2010.

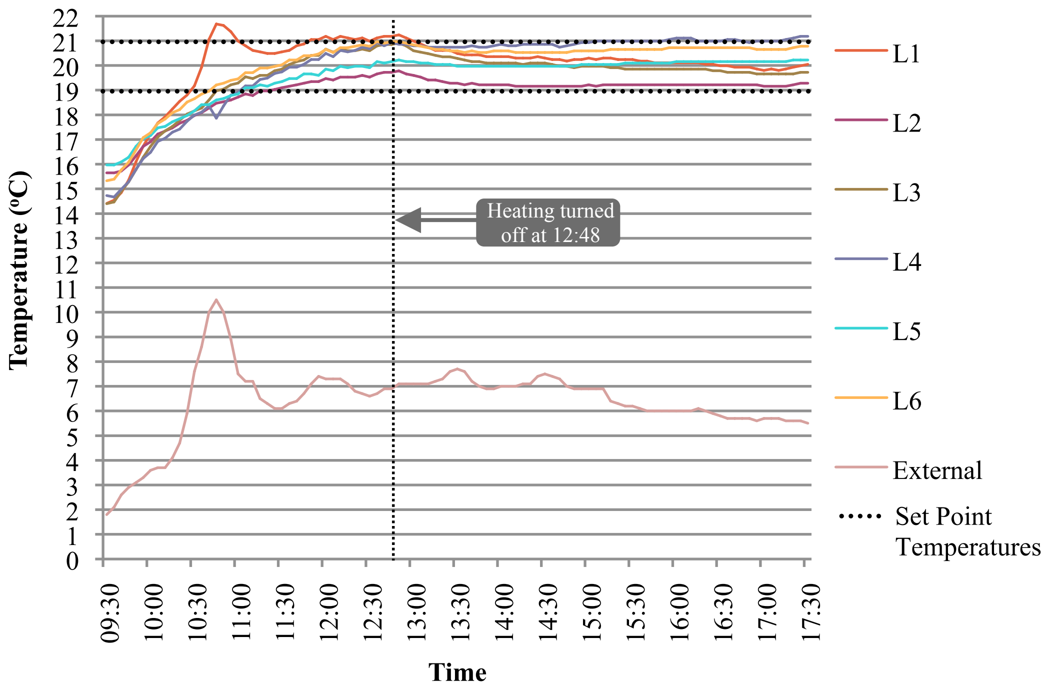

Figure 3.8 March 8, 2010 (Closed Door) Indoor and External Temperatures

There is an overall rise in temperature from start of business hours to roughly 13:00, which coincides with the period that the heating is used. After this point, temperatures inside the store remain relatively constant staying within the recommended temperature range.

A peak can be observed in location L1 which also corresponds to the peak in the external temperature, this may be due to a brief warm period in the morning due to solar gain.

The first instance when all locations are within the thermal comfort range happens at 11:25, however the heating continues to operate until the upper temperature set point is reached which occurs at 12:48.

Readings from the temperature sensors located L2 show the lowest temperature readings, likely due to its location directly in front of the door.

Figure 3.9 below displays the temperature readings gathered for the open door case.

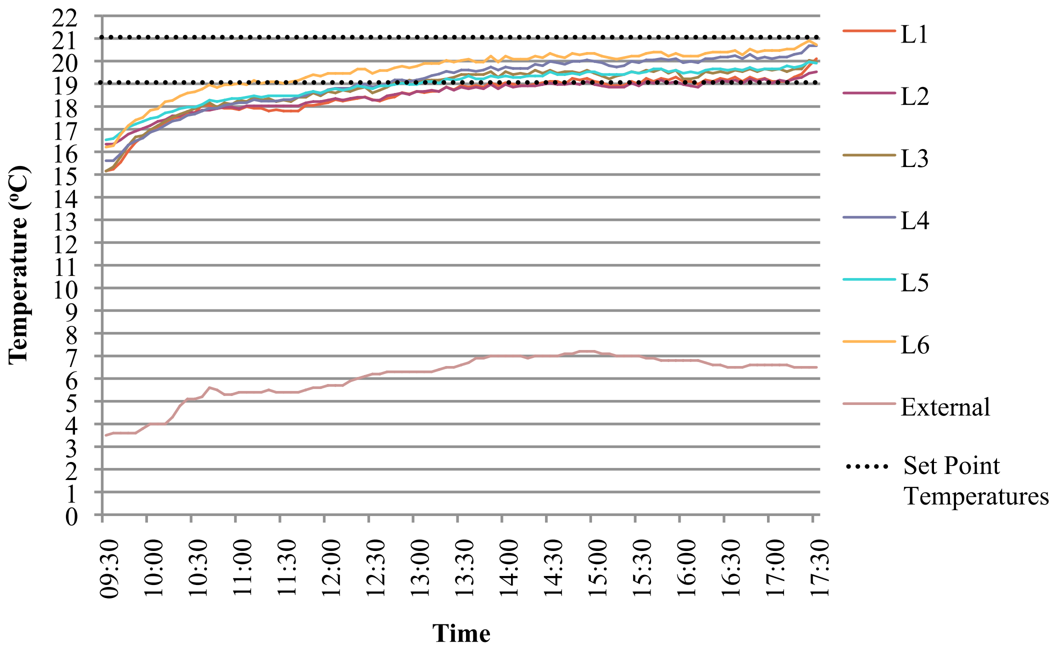

Figure 3.9 March 11, 2010 (Open Door) Indoor and External Temperatures

A similar trend of increasing temperatures can also be observed, however the time it takes for all temperature sensors to reach within the recommended temperature range is longer. Although this point was reached at 14:30, the heating was not turned off due to the upper set-point never being reached.

It can also be observed that after bringing the inside temperature to a certain level, the temperatures remain constant despite the continued operation of the heating, displaying the ineffectiveness for both the air curtain and the heating equipment to continue to heat the store.

To further investigate differences between the front and back of the store, Figure 3.10 displays the temperature at the front, which is the average of sensors L1, L2, L3 and the back which is the average of and the back is L4, L5, L6.

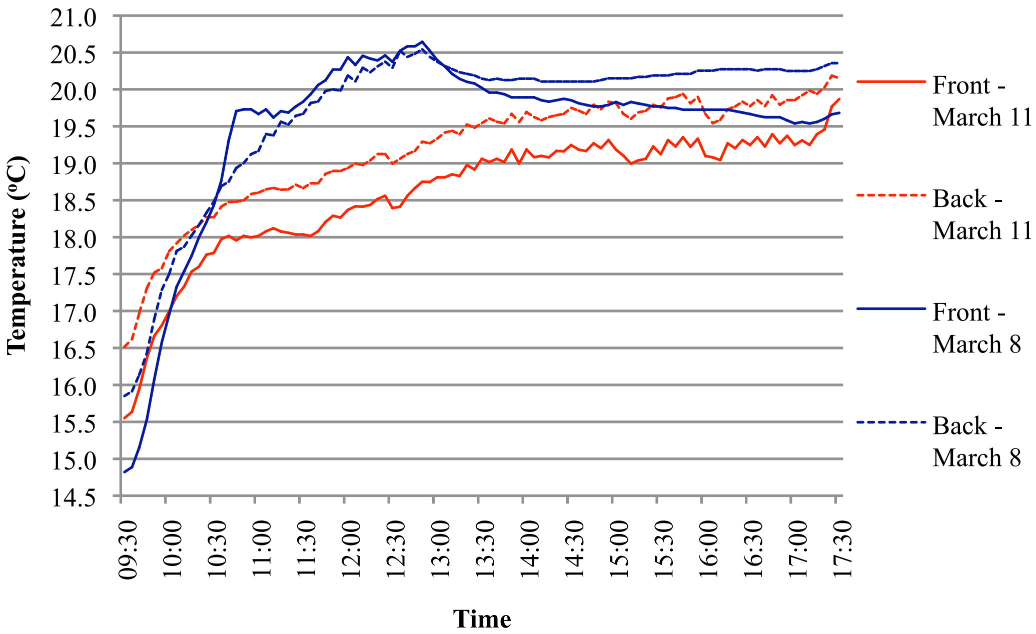

Figure 3.10 Temperature differences between front and back of the stores

It can be seen that for March 8, the case when doors were closed, the heating equipment is able to heat the store uniformly. Once the heating is turned off the drop in temperature of the front is 1 ^{o}C over the course of five hours due to infiltration of cold air each time doors are opened and the heat loss through the single glazed storefront. The back of the store drops slightly in temperature but tends to stay constant for the rest of the day due to higher concentration of lighting located at the back.

For the open door case, the operation of the air curtain and the constant heating throughout the whole day increases the temperatures at the front and back with the same trends observed both at the front and the back with a constant difference of roughly 0.5 ^{o}C.

3.3.2 Effect of External Conditions on Indoor Temperatures

The effect of outside temperature on internal temperatures for different door configurations will be investigated.

For closed door cases, March 1st and March 8th which both have the same measured average wind speed of 0.1 m/s, but averaged outside temperatures of 10.8 ^{o}C and 4.9 ^{o}C respectively will be used. Figure 3.11 displays the differences in internal temperatures.

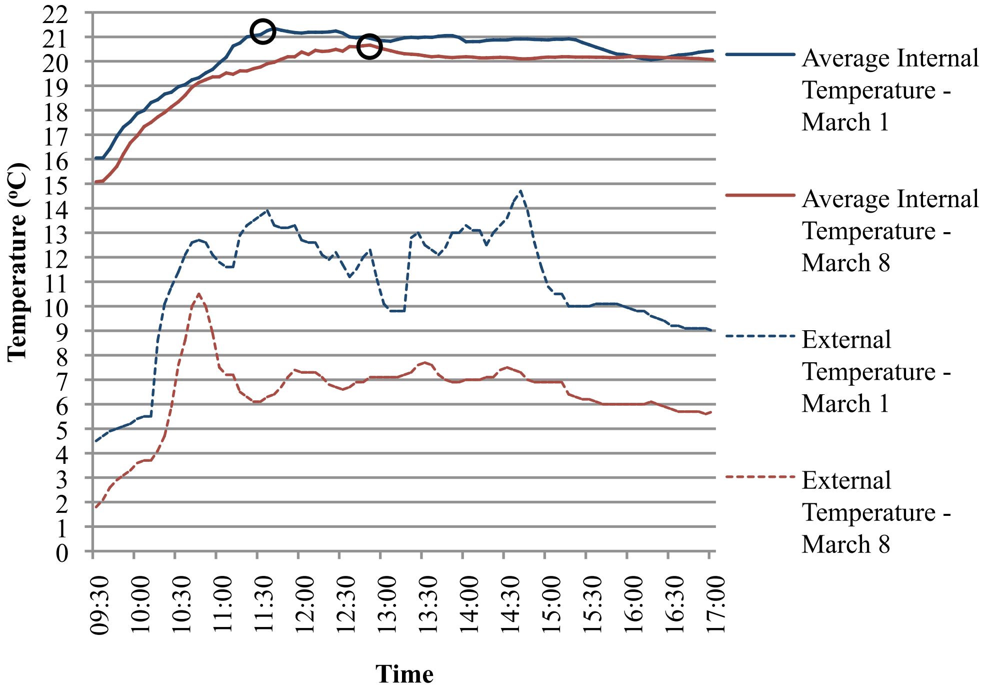

Figure 3.11 Average Internal Temperature differences for different outside temperatures for Closed Door Cases

From Figure 3.11, it can be seen that the difference in external temperatures increases after 11:00 and continues throughout the day with a slight decrease at 12:45. The circles indicate when the upper set point was reached. For March 1st it was 11:34 and for March 8 this was 12:48.

The changes in internal temperature due to external conditions can be inspected more closely by looking at the time period after heating is turned off; between 13:00 and 15:00. The average difference in external temperature was 5.2 °C corresponding to an internal temperature difference of 0.7 °C. It is observed even after heating has been turned off that the internal temperature remains within comfort levels for the remainder of the day.

3.4 Energy Performance of the Ryman Stationary during the Heating Season

3.4.1 Energy Consumption and Effect of External Conditions

The monitoring study conducted during the heating season for the Ryman Stationary Store was carried out between 25th February 2010 and 16th March 2010. Figure 3.12 below shows the total energy consumed during business hours.

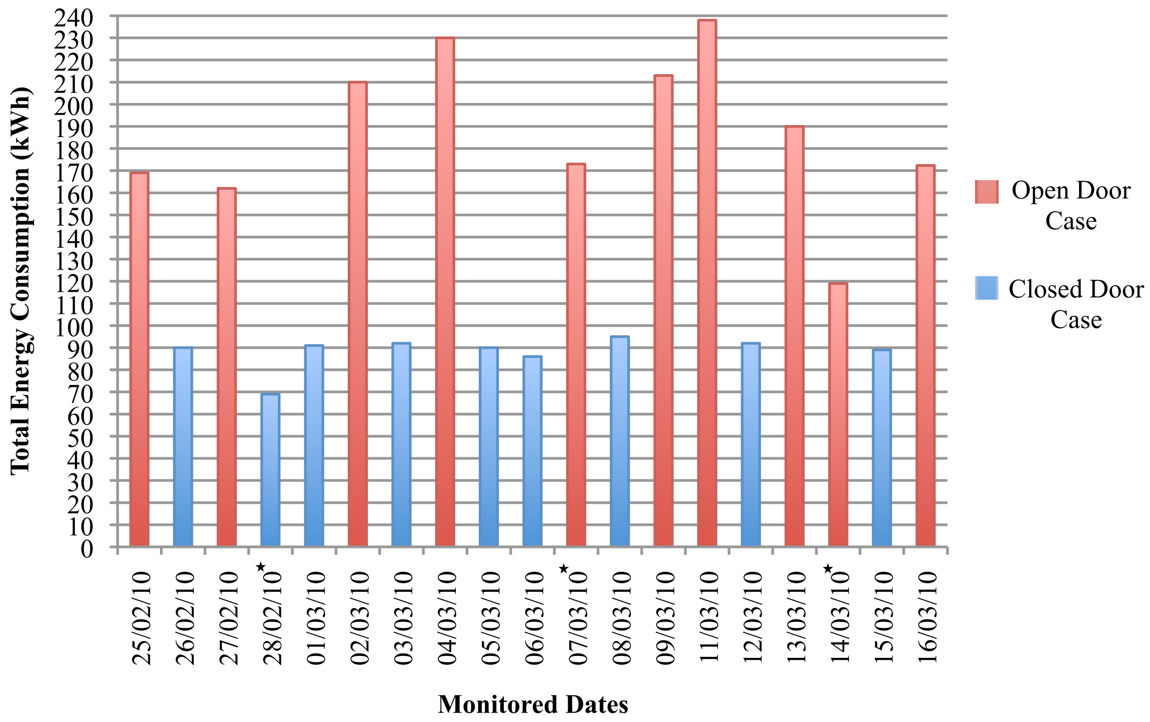

Figure 3.12 Monitored Energy Consumption for Ryman Stationary during Heating Season

Figure 3.12 presents similar findings as the Cambridge Toy Shop, the energy consumption during open door days are significantly higher. The differences in mean energy between the different configurations are shown in Table 3.3.

Table 3.3 Mean Energy Consumption of Closed and Open Door Cases during the Heating Season

	Mean Energy Consumption for Closed Door Cases (kWh)	Standard Deviation for Closed Door Cases (kWh)	Mean Energy Consumption for Open Door Cases (kWh)	Standard Deviation for Open Door Cases (kWh)
Weekdays & Saturdays	91	3	198	29
Sundays	69	N/A	146	N/A

The difference between mean energy consumption for weekdays and Saturdays is 107kWh, whereas for Sundays it is 77 kWh. The standard deviation between the open door cases is 29 kWh; whereas the closed door cases it is 3 kWh. This difference in standard deviation can be investigated further by examining the effect of external conditions on energy. Figure 3.13 and Figure 3.14 correlate the measured energy consumption and the external environmental conditions.

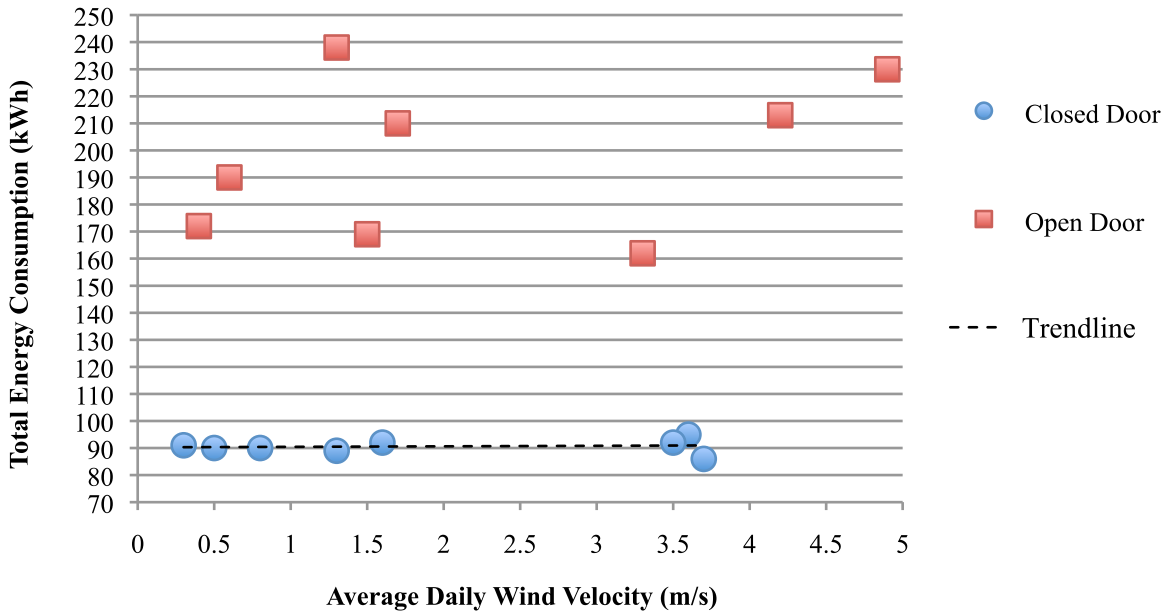

Figure 3.13 Effect of Wind Velocity on Total Energy Consumption during Heating Season for the Ryman Stationary

Comparable to the Cambridge Toy Shop, the wind velocity has negligible effect on energy when doors are closed and seem to have no trend when doors are open.

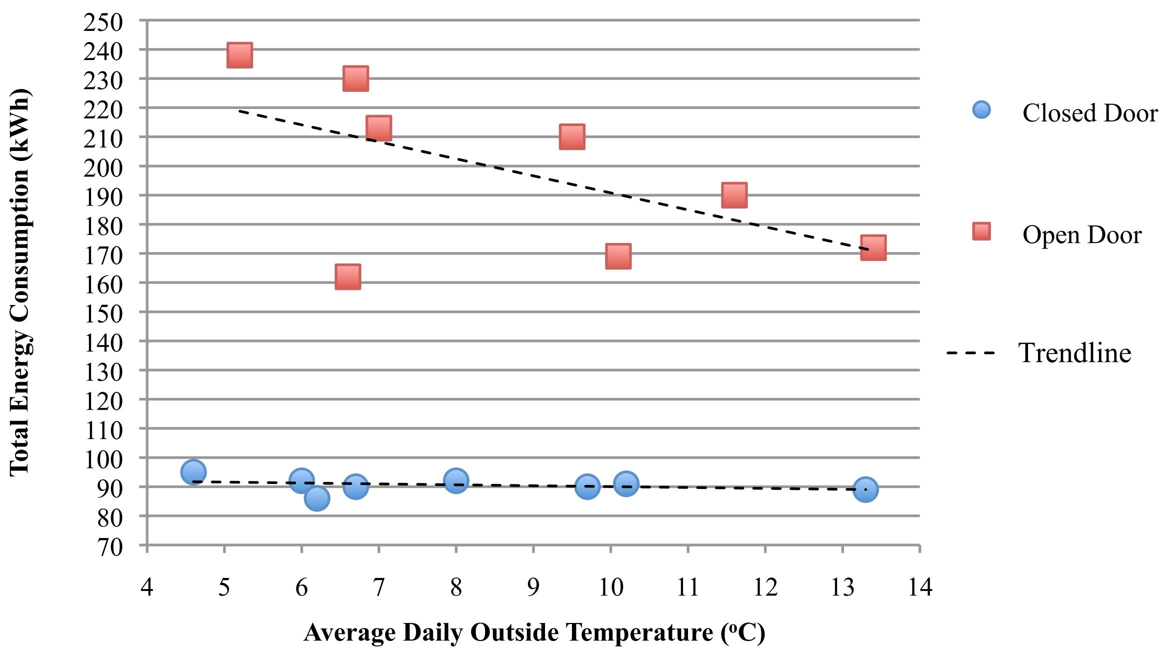

Figure 3.14 Effect of Outside Temperature on Total Energy Consumption during Heating Season for the Ryman Stationary

Figure 3.14 shows that there is a decrease in energy consumption as the outside temperature increases. As expected, when outside temperatures are lower, the convective losses due to infiltration when doors are opened by customers and the conductive heat losses through the single glazed display require the heating to operate for longer to bring internal conditions to the desired temperature range.

3.4.2 Energy Demand Profiles for Different Door Configurations

Metered energy demand profiles can identify the causes for the difference in mean energy consumption between different door configurations. Two sample days with similar external conditions were chosen. The external conditions for the selected days are summarized in Table 3.4.

Table 3.4 Comparison of External Conditions of Closed and Open Door Cases for Ryman Stationary

	March 3, 2010	**March 11, 2010**
Door Status	Closed	Open
Average Outside Temperature (°C)	6.0	5.2
Daily Minimum (°C)	2.6	1.4
Daily Maximum (°C)	9.4	7.3
Average Wind Speed (m/s)	1.6	1.3

Figure 3.15 displays the energy profile gathered from power meter data for March 3, 2010. The lighting load between 8:15 to 9:00 is due to the staff being present in the store before opening hours. The heating equipment was operating from 9:00 to 10:14, a period where the mean load was 16.7 kW.

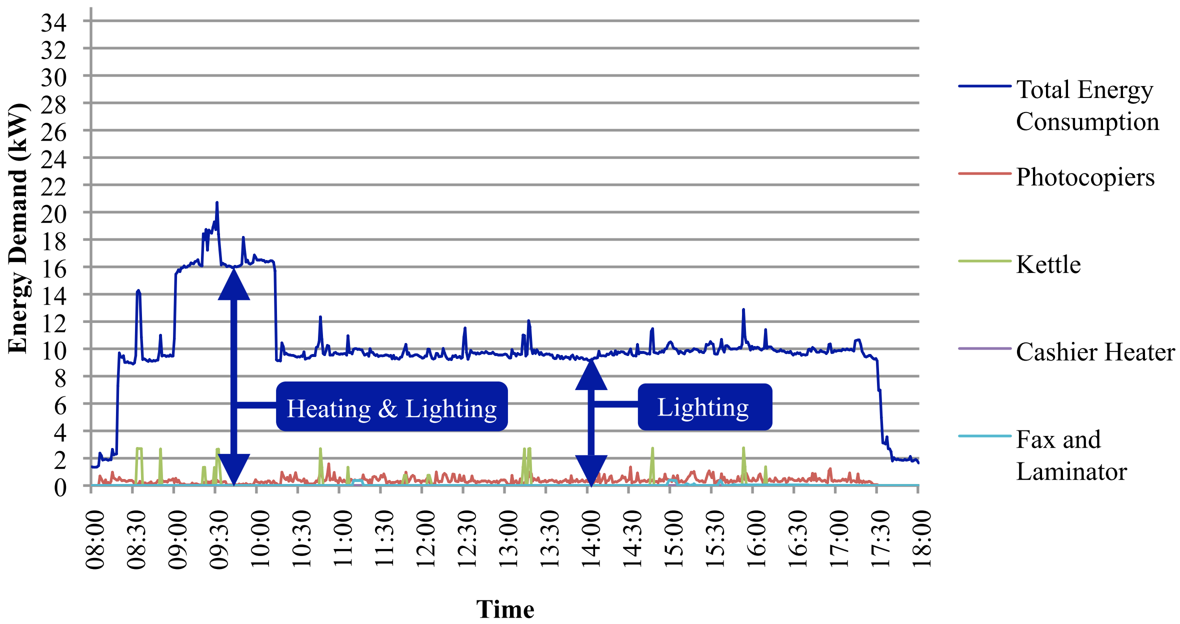

Figure 3.15 Energy Consumption Profile for March 3, 2010 (Closed Door Case)

Figure 3.16 represents the energy profile during March 11, 2010. The load throughout the day is on average 28.1 kW, it is comprised of the heating, lighting, three air curtains and the cashier heater. Similar to the Cambridge Toy Shop, when the doors were open the set-point was never reached hence the continued operation of the heating equipment throughout the whole day.

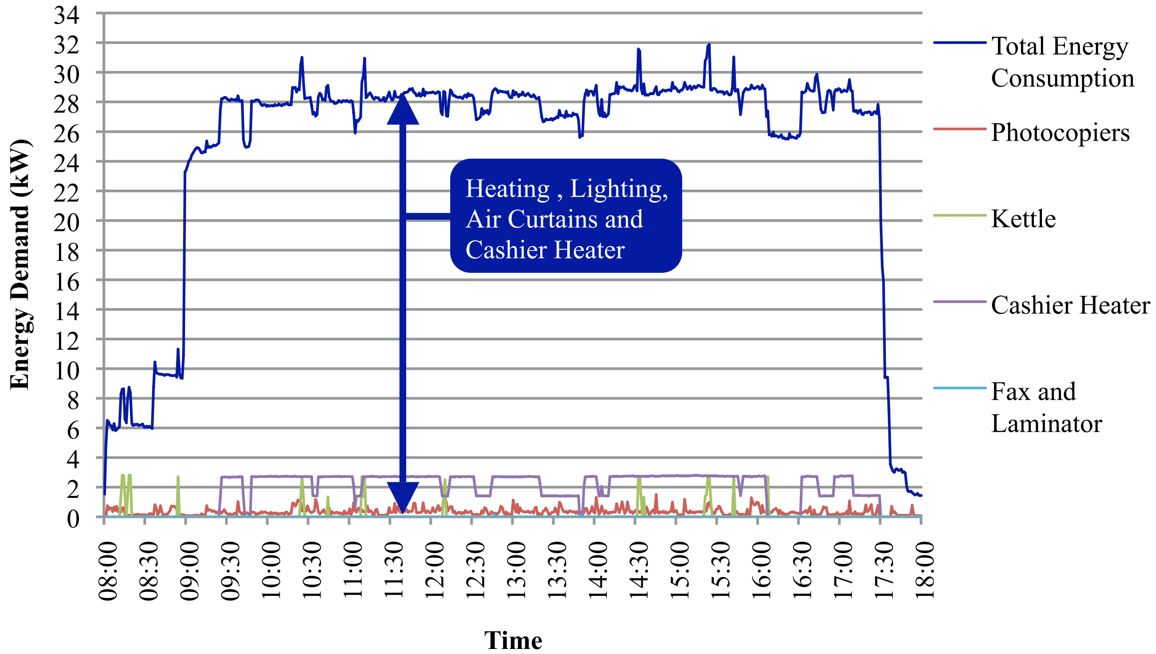

Figure 3.16 Energy Consumption Profile for March 11, 2010 (Open Door Case)

To assess the individual loads separately, it is useful to breakdown the total energy consumption into each component. Figure 3.17 displays the energy consumed for each load separately.

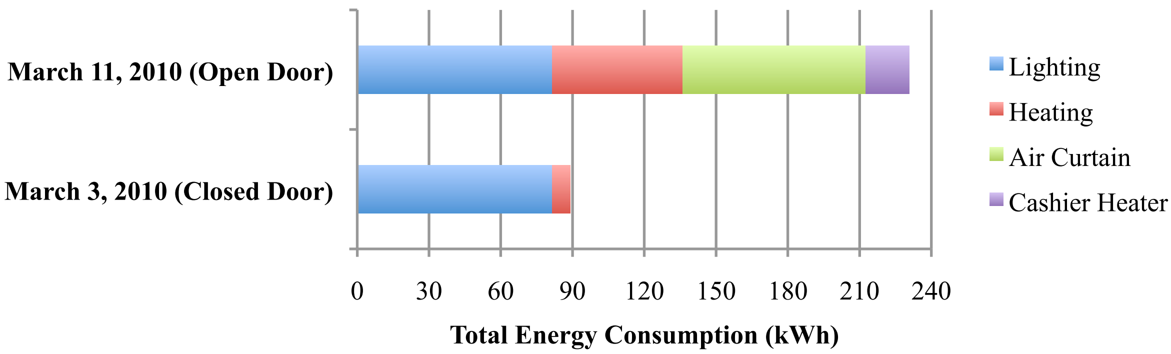

Figure 3.17 Breakdown of Energy Consumption

The calculated energy difference between March 11th and March 3rd is 142 kWh. This is comprised of the operation of three air curtains for eight hour and a half hours consuming 76.5 kWh, the additional seven hours and forty-five minutes use of the heating equipment totaling 47 kWh and the usage of the cashier heater 18.3 kWh.

The data gathered from the power meters indicate the various loads; the heating load is 6.4 kW when both A/C units are running on the manual set heating controls. The air curtains each consume 3 kW, cashier heater 2.7 kW and the largest contribution to energy consumption is due to the lighting, which consumes 9.6 kW.

The total energy consumed on March 11th was 231 kWh, while for March 3rd it was 89 kWh. This difference in energy consumption corresponds to a total energy difference of 61.5 %.

3.5 Investigation of Internal Conditions of the Ryman Stationary during the Heating Season

3.5.1 Thermal Comfort Levels

In this section the thermal comfort levels, considering temperature and relative humidity for Ryman Stationary will be presented. The days used to compare energy performance, March 3rd and March 11th are also used for the comfort study. Figure 3.18 shows the locations of the temperature & humidity sensors.

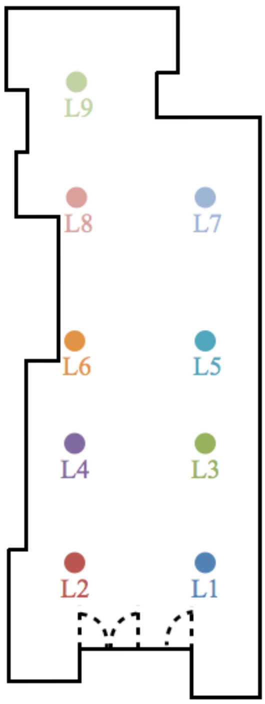

Figure 3.18 Locations of the Temperature Sensors in the Ryman Stationary Store

Figure 3.19 shows the measured indoor temperature at various locations and the external temperature on March 3, 2010.

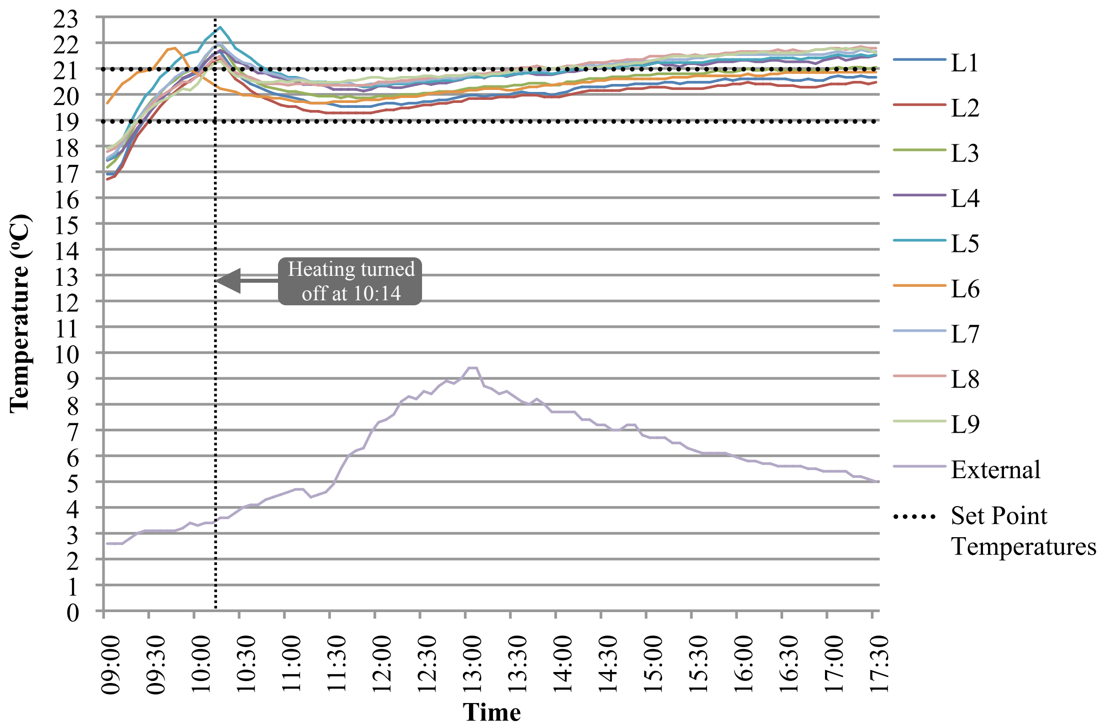

Figure 3.19 March 3, 2010 (Closed Door) Indoor and External Temperatures

There is an increase in temperature throughout the heating period 9:00 to 10:14. After heating is turned off, for a short period the overall temperatures exceed 21 °C. The internal gains appear to contribute to the overall increase in temperature throughout the day, from 12:00 to 17:30 the average increase in temperature is 1.2 °C. Figure 3.20 presents the indoor temperature trends for the open door cases.

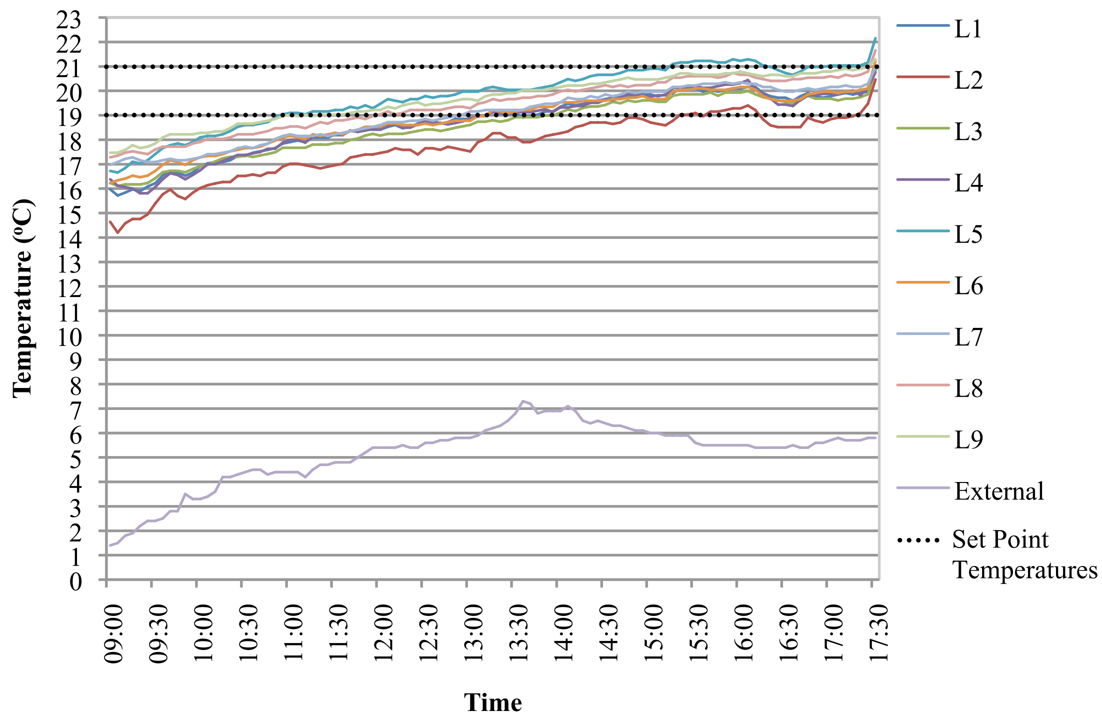

Figure 3.20 March 11, 2010 (Open Door) Indoor and External Temperatures

As shown in Figure 3.20, at 14:00 all temperatures exceed 19 °C. Similar to the Cambridge Toy Shop the upper set point temperature, in the open door case was never reached, therefore heating was not turned off.

The Ryman Stationary's shop floor has a depth of 21.85 m, therefore it is important to investigate possible differences in indoor temperatures at the store front and back. Figure 3.21 illustrates the measured averaged temperatures at the locations. The temperature at the front is the mean temperature of sensors L1, L2, L3, L4 and the back is the mean of sensors L5, L6, L7, L8, L9.

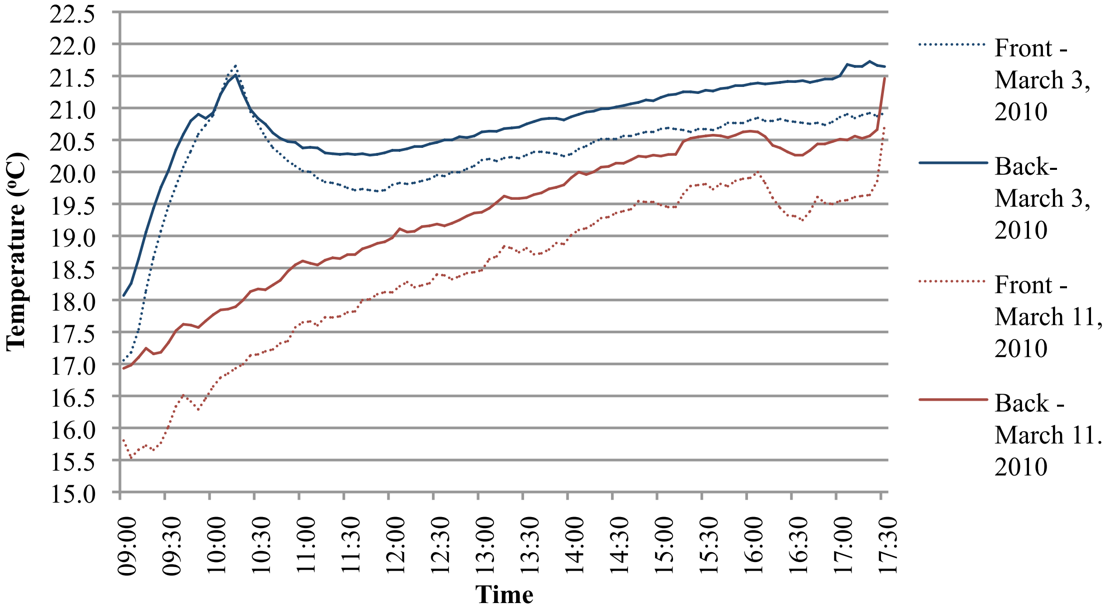

Figure 3.21 Temperature differences between front and back of the stores

As shown in Figure 3.21, for the closed door case when the heating is turned off, the temperatures at the front and back of the store increase after 12:00 with an average difference of 0.55 °C. The temperatures for the open door cases also increase through the day with an average difference of 0.87 °C.

3.5.2 Effect of External Conditions on Indoor Temperatures

The effect of the outside temperature on the internal conditions for closed door cases will be shown in Figure 3.22. The chosen closed door days are March 8th and March 12th, which have comparable wind speeds of 3.6 m/s and 3.5 m/s but have average outside temperatures of 4.6 °C and 8 °C respectively.

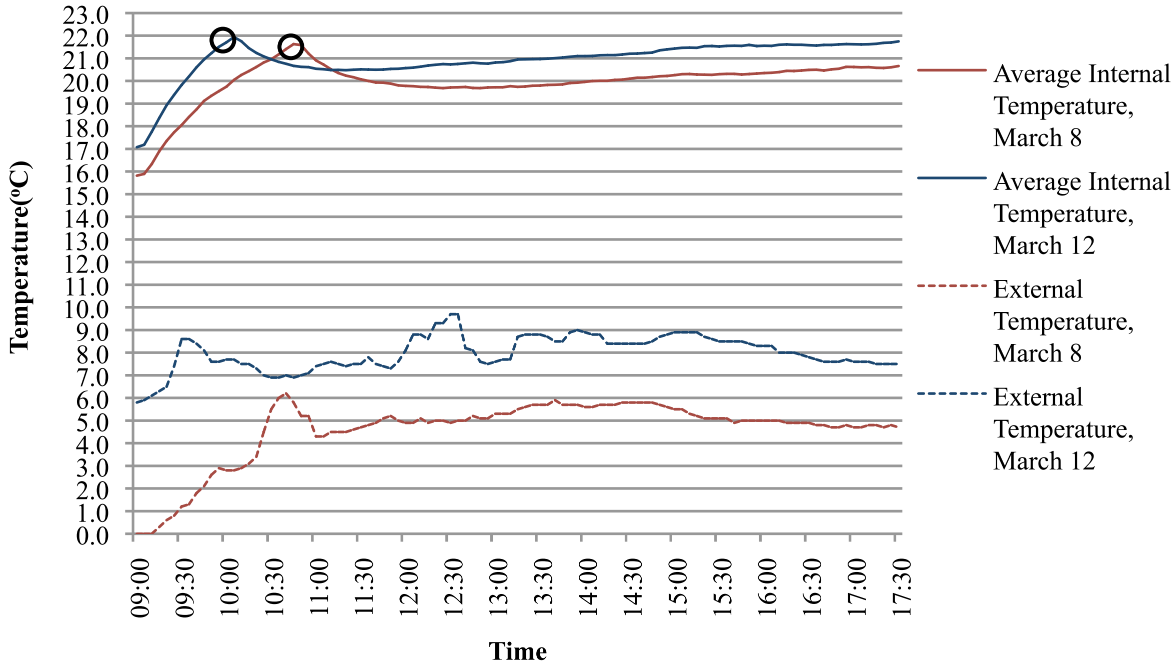

Figure 3.22 Average Internal Temperature differences for different outside temperatures on Closed Door Case

The circles indicate when the upper set point was reached. For March 12th it was 10:00 and for March 8th this was 10:46. Between 12:00 and 17:30 both internal temperatures remain relatively constant with an average increase of 1.1 °C for March 12th and 0.8 °C for March 8th.

3.6 Estimated Annual Savings

The annual savings that the monitored stores can achieve when doors are shut during winter can be estimated using the findings of the current study and historic weather data.

It was found that when the mean outside temperature during business hours is above 14 °C no heating was used in either store. Historic weather data from a weather station located 1.5 miles from stores was used to calculate the number of days that were below 14 °C in the past five years. Once this total was calculated, $\overline{T}_{out}$ which is the mean outside temperature during business hours of all filtered days was computed and summarised in Table 3.5.

Table 3.5 Number of days when average outside temperature is below 14°C

	2005	2006	2007	2008	2009
Number of days $\overline{T}_{out}$ < 14 °C	144	149	137	169	152
Mean $\overline{T}_{out}$ of filtered days (°C)	8.6	8.8	9.8	9.5	8.2

The next step was to determine the difference in the measured energy consumption between two days with different door configurations when $\overline{T}_{out}$ is comparable to the temperatures found in Table 3.5.

This difference multiplied by the number of days would indicate the annual energy savings that could be achieved by closing the doors during the heating season.

Table 3.6 and Table 3.7 present the annual savings in energy, reduction in carbon emissions and cost that would have been achieved in that past five years.

Table 3.6 Estimated Annual Savings for the Cambridge Toy Shop

	2005	2006	2007	2008	2009
Energy Savings (kWh)	5040	5215	5069	6253	5320
Carbon savings (Kg CO_2 equivalent)	2742	2837	2757	3401	2894
Cost Savings (£) (calculated based on 9.7 pence per kWh)	489	506	492	607	516

Table 3.7 Estimated Annual Savings for the Ryman Stationary

	2005	2006	2007	2008	2009
Energy Savings (kWh)	17136	17731	13563	20111	18696
Carbon Savings (Kg CO_2 equivalent)	9322	9646	7378	10940	10170
Cost Savings (£) (calculated based on 9.7 pence per kWh)	1662	1720	1316	1951	1814

The differences in savings between the chosen years exist due to fluctuations in annual temperature. The mean cost savings of the past five years would total £ 1693 (£ 11.06 / m^2) for Ryman Stationary and £ 522 (£ 3.3 / m^2) for the Cambridge Toy Shop. Although both stores are similar in floor area, the savings per m^2 are noticeably different. The energy savings per door can be calculated for both stores, which is £564 /per external door for the Ryman Stationary and £522 /per external door for the Cambridge Toy Shop. This method of calculating potential energy savings is more suitable, since the energy consumption of air curtains have a significant contribution to the energy demand when doors are open.

3.7 Estimated Thermal Comfort during the Heating Season

To assess thermal comfort for different door configurations during the heating season, the outside temperature of a typical winter day must first be calculated. Using Table 3.5, the mean outside temperature during business hours over the past five heating seasons was 9 ^oC.

From the monitored period, days comparable to this outside temperature were selected for comparison. The percentage of business hours that the mean internal temperature was below 20 ^oC was calculated. This temperature was chosen as the mean temperature of the recommended temperature range by CIBSE, which states that during winter retail buildings should operate between $19^{o}C$ – $21^{o}C$.

The Cambridge Toy Shop on March 5th (Closed Door, T_{out}=10 ^{o}C) had 19 % of business hours below 20 ^{o}C, whereas for March 4th (Open Door, T_{out} =8.5 ^{o}C) had 44% of business hours below this temperature.

A similar comparison for Ryman Stationary shows that for March 5th (Closed Door, T_{out} = 9.7 ^{o}C) had 6 % of business hours below 20 ^{o}C, whereas for March 2nd (Open Door, T_{out} = 9.5) had 63% of business hours below 20 ^{o}C.

There is a significant difference in thermal comfort between the different door configurations. Both stores when doors are open are operating roughly half of business hours below 20 ^{o}C. This may have effect on staff discomfort and in some cases may cause staff to use additional heating as seen in the energy profile for Ryman Stationary in Section 3.4.2.

3.8 Customer Footfall and Transaction Findings

The customer footfall and transaction count were calculated using the data from two weeks, between the dates 27th February 2010 to 12th March 2010. The days of the week that closed doors cases could be run were limited due to the weekly operation of the stores, i.e. stock deliveries that required doors to be open. The number of days that doors could be left open was also constrained due to staff complaints. During this two week period, six open door days and eight closed door days for Ryman Stationary, five open door days and nine closed door days for the Cambridge Toy Shop were monitored. Table 3.8 shows the average footfall and transactions for the days with different door configurations.

Table 3.8 Customer Footfall and Transactions

	Average Open Door Footfall	Average Closed Door Footfall	Average Open Door Transactions	Average Closed Door Transactions
Cambridge Toy Shop	421	354	99	77
Ryman Stationary	985	1255	529	527

It can be seen from the gathered data, the footfall for the Cambridge Toy Shop increased 19 % when doors were left open. However for the Ryman Stationary, during open door days the footfall was lowered by 22%. The transaction count reveals that for both stores that there is an increase in transaction rate. However, this increase is 29 % for the Cambridge Toy Shop and only 0.4 % for the Ryman Stationary.

Chapter 4

Conclusions

4.1 Conclusions

This study was undertaken to quantify the energy savings and assess thermal comfort in retail stores when external doors are kept closed during the heating season. The present study has shown that significant energy savings can be achieved when doors remain shut during the winter. The gathered energy consumption data indicate that an average savings of 30 % for Cambridge Toy Shop and 54 % for Ryman Stationary can be achieved during the heating season by keeping external doors closed. These savings are attributed to the reduction in the space heating load and eliminating the need to operate air curtains.

The sensitivity of energy demand to external conditions was also assessed in this study. For open door cases, findings show that higher average outside temperatures result in lower energy demands. This is due to the reduced space heating load. The wind velocity on the other hand had no apparent effect on the energy consumption for open doors cases. For closed door cases, the results indicate that both outside temperature and wind speed during the heating season have a negligible effect on the energy consumption and that energy demand remains relatively constant throughout a wide range of external conditions.

The thermal comfort conditions inside the stores for open door days and closed door days were examined to determine if the same thermal comfort levels could be achieved. When doors were left open, the results indicate that the usage of heating equipment and air curtains failed to provide the desired thermal comfort throughout the day. Internal temperatures take a longer time to reach comfort levels. In addition, this can result in staff relying on additional heating equipment, thus increasing total energy consumption.

The results of this study can have an important application for future operation of retail stores. The empirical findings in this study provide the necessary information for retailers to understand the benefits of one out of several energy efficiency measures i.e. keeping external doors closed during the heating season. In order to reduce operating energy costs, each business must assess their specific conditions and the energy efficiency measures at their disposal. Nevertheless, the energy savings identified in this study therefore establish closing doors as an important energy efficiency measure that stores can implement to reduce their operating costs. The loss of thermal comfort during a considerable period during the day also suggests that open doors can affect staff well-being and customer comfort.

Taken together, these findings suggest closing doors is an effective way to reduce energy consumption while at the same time improving internal comfort conditions.