Investigation of Black Soot Staining in Houses

April 2000

Submitted to:

Don Fugler
Canada Mortgage and Housing Corporation
National Office
700 Montreal Road
Ottawa, ON, K1A 0P7

Submitted by:

Gord Cooke
44 Darren Crescent
Cambridge, ON, N3C 3Y1

This project was carried out with the assistance of a financial contribution from Canada Mortgage and Housing under the terms of the External Research Program. The views expressed are those of the author and do not represent the official views of CMHC.

Acknowledgements

Gord Cooke and Air Solutions Inc. would like to thank the families who allowed us into their homes and agreed to partake in our study of black soot staining in their houses.

Also we are grateful to the builders for their cooperation and assistance in selecting suitable participants for this study.

We acknowledge with thanks, the contribution of Lex Scientific Inc., which carried out our testing, and to Kim O'Neill for her technical advice and help designing the lab testing parameters.

Abstract

Many homeowners have experienced problems with dark streaking on carpets or sooting of walls, furnishings and other house components. In most cases where these streaking problems have occurred, homeowners have reported they burn candles. This study was designed to provide some insight into the contribution of candles to sooting problems. The contractor located five houses with both streaking problems and regular candle use. Samples of the dust or soot were collected and analyzed by an independent laboratory in an attempt to identify pollutant sources. The laboratory also burned samples of the candles used in the individual houses and tried to match the soot collected in the laboratory with the samples taken from the houses. In addition, information on sooting occurrence and cleanup was collected from candle manufacturers, cleaning companies and homebuilder associations.

Table of Contents

Executive Summary

Indoor air quality investigators are often asked to investigate streaking, staining or sooting problems in houses. Such stains or streaks are usually characterized as black marks on light coloured carpets along baseboards at either exterior or interior walls, at doorways and behind furniture, black smudges on window frames, cabinets and plastic furnishings and sometimes shadowing of studs on exterior wall drywall. These problems seem to be more prevalent in new homes but older homes are also affected. Much attention has been paid to identifying the source of the black material causing the stains. Most building scientists agree it is most often a carbon soot from a combustion source. Potential combustion sources in houses include furnaces, fireplaces, water heaters, gas dryers, gas ranges, smoking, vehicle exhaust from attached garages and candle burning.

To date there are no simple, diagnostic tests to positively identify the source of soot. That is, while microscopic investigation can indicate material is from a combustion source generally, identifying a specific combustion source requires sampling and laboratory techniques that are impractical in residential investigations. However, homeowners and other interested parties – their builders, cleaning contractors, mechanical contractors, and insurance agents – desire more definitive answers before they contemplate changes or clean up and assess liability. Specifically, homeowners are very skeptical about the potential of candle burning to cause widespread staining throughout their homes.

This study was designed to investigate sooting problems in houses where occupants reported regular burning of candles. Samples of stained carpets, filters and other materials as well as swab samples of black dust or soot were taken from five homes. In addition, samples of commonly burned candles in the homes were burned in a laboratory. The objective was to try and match the soot from the candles burned in the laboratory to the materials found to be staining components in the houses. Various laboratory techniques were used to try and establish a practical, cost effective test protocol for identifying soot. In addition, a thorough indoor air quality audit was conducted on each home to identify other potential pollutant sources and contributing factors. This information could provide IAQ investigators with diagnostic and testing techniques that would help them corroborate or prove to clients the pollutant source of the streaks and stains in their homes. The study also included a search of industry information to uncover best practices for clean up and control of soot or staining problems.

While the laboratory was able to consistently identify materials consistent with candle soot or residue using standard microscopic investigations, they were unable to establish a link between stained material in homes with the soot from candles burned in those homes. Samples from three of the five homes were identified as having significant quantities of candle soot. Of great interest, even samples that appeared to be very black in colour were, in fact, made up of a wide array of common household dust components including drywall dust, human and pet dander, carpet fibers etc. While on their own these common pollutants might appear gray in colour, when combined with the candle soot, the entire samples looked like large quantities of black material. In the houses where candle soot was not identified, the most common element in the samples was drywall compound or texture coat dust.

Each of the houses had many elements that would add to the total dust load in the house including furry pets, high traffic areas, a lot of carpets, interior renovation projects and outside construction work. The analysis of the samples would indicate these other dust sources were strong contributors to the streaking problems.

The building industry has a good understanding of why stains and streaks develop in specific locations. Air flow patterns developed by forced air heating systems and air leakage characteristics of homes, combined with more subtle air movement due to thermal currents and surface adhesion forces, determine where dust and soot will be deposited. The soot deposition patterns in the houses studied were consistent with these known airflow patterns. The three houses with identified candle soot had streaking problems on vertical surfaces such as window frames and plastic cabinet components and other surfaces such as light fixtures and appliances, in addition to carpet streaking. The houses where candle soot was not identified, had streaking of carpets and furnace grilles only. This would indicate the smaller soot particles are affected by the more subtle air flow patterns of thermal currents and surface adhesion, where as, larger dust particles such as drywall compound dust are more likely to be affected and deposited as a result of more significant air flows such as those produced by forced air systems or air leakage paths.

The clean up of soot problems has proved to be very difficult. While surfaces and walls can generally be washed or in the worst case repainted, carpet cleaning is more difficult. Organizations representing the carpet and cleaning industry do have specific cleaning procedures but they are all prefaced with statements that the cleaning will simply improve the appearance and are unlikely to remove the stains completely. The staining process is complicated by chemical interactions of the soot with other particulates and the carpet fibers. Carpet fibers are, for the most part, made from petroleum derivatives. The hydrocarbon soot may chemically attack or bond to the carpet fibers, changing their appearance or colour permanently and thus cleaning will never eliminate streaks.

Given that clean up is difficult, avoidance and control are very important. Similar to other indoor air quality problems, the most effective way to avoid a streaking or staining problem is to eliminate all potential soot sources. Eliminating the burning of candles, ensuring combustion appliances are venting correctly and/or are direct vent, sealed combustion, avoiding idling of vehicles in attached garages, and avoiding the use of, or properly venting, gas ranges.

Résumé

On demande fréquemment aux investigateurs de la qualité de l'air intérieur d'examiner les taches en traînée et les taches fuligineuses ou de suie dans les habitations. De telles souillures se caractérisent habituellement par des taches noires sur les moquettes de teinte pâle près des plinthes au bas des murs extérieurs ou des cloisons intérieures, sur les cadres des portes et sur les murs derrière le mobilier, par des souillures sur les cadres de fenêtre, les armoires et les objets mobiliers de plastique, et à l'occasion par le spectre des poteaux sur les plaques de plâtre des murs extérieurs. La fréquence de ces problèmes semble plus élevée dans les maisons neuves que dans les maisons existantes. Beaucoup d'efforts ont porté sur l'identification de la substance noirâtre à l'origine des ces taches. La majorité des spécialistes du bâtiment s'entend sur le fait qu'il s'agit la plupart du temps de suie de carbone que produit la combustion incomplète d'un combustible. Dans les habitations, les produits de la combustion proviennent habituellement des sources suivantes : les générateurs de chaleur, les foyers à feu ouvert, les chauffe-eau, les sécheuses et les cuisinières à gaz, les cigarettes, les gaz d'échappement des véhicules moteurs dans les garages attenant et les bougies.

Il n'existe pas, à l'heure actuelle, d'analyses simples permettant de déterminer avec certitude la source d'un échantillon de suie. Même si un examen microscopique peut généralement indiquer que l'échantillon provient d'une source de combustion, l'établissement de sa provenance exacte requiert des techniques d'échantillonnage et de laboratoire qui ne sont pas pratiques dans les enquêtes résidentielles. Cependant, les propriétaires, ainsi que les autres intervenants tels que les constructeurs, les services de nettoyage, les entrepreneurs en installations mécaniques et les agents d'assurance désirent obtenir des réponses claires avant d'effectuer des modifications, d'entreprendre le nettoyage ou d'évaluer la responsabilité des parties. Les propriétaires-occupants, en particulier, ont des doutes quant à la possibilité que les bougies soient à l'origine des nombreuses taches observées dans leur maison.

On a conçu l'étude afin d'enquêter sur les problèmes de taches de suie dans les maisons où les occupants ont indiqué qu'ils faisaient souvent brûler des bougies. Des échantillons de moquettes souillées, des filtres et d'autres matériaux ainsi que des épreuves sur écouvillon de poussières noires ou de suie ont été prélevés dans cinq maisons. De plus, on a fait brûler en laboratoire des échantillons de bougies utilisées habituellement dans les maisons afin de faire le rapprochement entre la suie produite par les bougies en laboratoire et celle prélevée dans les maisons. On a utilisé différentes techniques de laboratoire pour établir un protocole d'identification de la suie qui serait à la fois pratique et économique. D'autre part, une vérification complète de la qualité de l'air intérieur a été menée dans chacune des maisons afin de repérer d'autres sources possibles de polluants et de facteurs contributifs. Ces renseignements pourraient fournir aux investigateurs de la qualité de l'air intérieur les techniques diagnostiques et d'essais leur permettant d'établir ou de corroborer pour leurs clients la source des souillures et des taches de suie relevées dans les maisons des ces derniers. L'étude comprenait aussi la recherche à même les informations produites par l'industrie pour tenter d'y découvrir les pratiques exemplaires utilisées pour le nettoyage et la prévention des taches de suie.

Même si en laboratoire on est parvenu systématiquement à confirmer à l'aide d'un examen normal au microscope que la substance était compatible avec la suie ou les résidus produits par des bougies, on n'est pas parvenu à établir un lien entre la suie présente sur les échantillons souillés et la suie produite par les bougies brûlées dans les maisons. Les échantillons provenant de trois maisons sur cinq comportaient des quantités importantes de suie de bougie. Fait intéressant, même les échantillons qui paraissaient très noirs étaient en fait composés d'un vaste éventail de particules de poussière domestique provenant des plaques de plâtre, des squames humains et animaux, de fibres de moquettes, etc. Pris individuellement, ces derniers paraissent gris, alors que combinés avec la suie de bougie, les échantillons complets prenaient l'apparence d'une forte quantité de matière noire. Dans les maisons où la suie de bougie était absente, l'élément le plus commun trouvé dans les échantillons était de la poussière de composé à joint ou de revêtement texturé.

Chacune des maisons comportait de nombreux éléments qui contribuaient à la charge totale des poussières : les animaux domestiques à poil, les aires de grande circulation, les nombreuses moquettes et les travaux de rénovation intérieurs et extérieurs. L'analyse des échantillons tend à démontrer que ces autres sources de poussières ont contribué largement à la formation des taches en traînée.

Dans l'industrie du bâtiment, on comprend bien la cause des taches en traînée à certains endroits précis. Les mouvements d'air produits par les systèmes de chauffage à air pulsé et les caractéristiques des fuites d'air des maisons, jumelés aux mouvements d'air plus subtils attribuables aux courants thermiques et au phénomène d'adhérence aux surfaces déterminent l'emplacement des dépôts de poussière et de suie. Les caractéristiques des dépôts de suie dans les maisons étudiées étaient compatibles avec ces mouvements d'air connus. Les trois maisons dans lesquelles on a prélevé de la suie de bougie comportaient, en plus des taches en traînée sur les moquettes, des taches en traînée sur les surfaces verticales des cadres de fenêtres et sur les composantes en plastique des objets mobiliers et d'autres surfaces comme les appareils d'éclairage et les appareils ménagers. Dans le cas des maisons dépourvues de taches de suie de bougie, on n'a trouvé des taches en traînée que sur les moquettes et sur les grilles du système de chauffage à air pulsé. Ces derniers cas semblent démontrer que les petites particules de suie subissent l'influence des mouvements d'air subtils liés aux courants thermiques et aux phénomènes d'adhérence aux surfaces, tandis que les particules grossières telles que les poussières de composé à joint sont susceptibles d'être déplacées et déposées par des mouvements d'air plus importants comme ceux produits par les systèmes de chauffage à air pulsé et par les fuites d'air.

Le nettoyage de la suie s'est avéré très difficile. Alors que les surfaces lisses et les murs peuvent habituellement être lavés ou, dans le pire des cas, repeints, le nettoyage des tapis se révèle ardu. Les organismes qui représentent l'industrie des moquettes et celle du nettoyage ont tous des procédés normalisés de nettoyage, mais ceux-ci portent la mention que le nettoyage ne fera qu'améliorer l'apparence de la moquette sans éliminer entièrement les taches. La suie et les autres substances particulaires présentes dans les fibres de moquettes interagissent chimiquement pour produire une tache complexe. Les fibres de moquettes étant fabriquées en grande partie à base de produits pétroliers, la suie d'hydrocarbures peut donc s'attaquer aux fibres de la moquette ou s'y

fixer, modifiant en permanence leur apparence ou leur couleur, si bien que le nettoyage ne pourra jamais éliminer totalement les taches en traînée.

Puisque le nettoyage est si ardu, on doit privilégier la prévention et la vérification. À l'image des problèmes de qualité de l'air intérieur, le moyen le plus efficace de prévenir les taches en traînée consiste à éliminer toutes les sources éventuelles de suie. Il faut donc éviter de faire brûler des bougies et s'assurer que les appareils de combustion, notamment les cuisinières à gaz, soient bien alimentés en air comburant, et soient munis d'un conduit d'évacuation approprié ou soient de type à combustion scellés. On évitera aussi de laisser tourner au ralenti les véhicules automobiles dans les garages attenants.

CMHC SCHL

National Office
700 Montreal Road
Ottawa ON K1A 0P7
Telephone: (613) 748-2000

Bureau national
700 chemin de Montréal
Ottawa ON K1A 0P7
Téléphone : (613) 748-2000

Puisqu'on prévoit une demande restreinte pour ce document de recherche, seul le résumé a été traduit.

La SCHL fera traduire le document si la demande le justifie.

Pour nous aider à déterminer si la demande justifie que ce rapport soit traduit en français, veuillez remplir la partie ci-dessous et la retourner à l'adresse suivante :

Le Centre canadien de documentation sur l'habitation
La Société canadienne d'hypothèques et de logement
700, chemin de Montréal, bureau C1-200
Ottawa (Ontario)
K1A 0P7

TITRE DU RAPPORT : _____

_____

Je préférerais que ce rapport soit disponible en français.

NOM _____

ADRESSE _____
rue app.

_____
ville province code postal

No de téléphone ( ) _____

1. Introduction

Awareness of air quality issues in Canadian homes has increased dramatically over the last few years. Initiatives and research by many organizations, including CMHC, The Lung Association and NRCan have helped homeowners and the building industry recognize the importance of indoor air quality. Furthermore, many private companies, including manufacturers of HVAC equipment and building products, cleaning companies and inspection service companies promote products and services related directly to improving indoor air quality.

One specific issue that is being identified with increasing frequency is the staining or streaking of carpets, walls and furnishings with a fine black dust or soot. This problem may be referred to or characterized as:

- Ghosting of wood stud members on the interior surface of drywall of exterior walls.
- Streaking of carpets along the perimeter of interior or exterior walls, under doors and around furnace vents.
- Black smudging on vinyl window frames, appliance surfaces, inside kitchen cabinets or on light fixtures.

Homeowners are often puzzled as to the source of the black material and why it accumulates where it does. Furthermore they find clean up is difficult and in the case of carpet streaks almost impossible. The building science community has a reasonable understanding of the issue. Investigations focus on identifying the source of the contaminant and explaining deposition patterns. In many cases the contaminant is identified as a carbon soot and immediately attention is directed towards combustion sources in the home. An increasingly common potential source is candle soot. In fact, literature on the topic suggests candle burning is the likely culprit in many cases. Despite the conclusions of air quality investigators, homeowners have a very difficult time believing candles could be the problem. They often cite the following objections:

- Candles have been burned for centuries in houses, why have they never heard of this before?
- They burned candles for years in other homes and never had a problem.
- Candle manufacturers don't give any indication of sooting or warning of problems.
- They don't burn candles all the time, only as little as a few hours a week.

According to the NAHB, "in a Florida study of soot accumulation, 27 of 28 families in problem homes reported burning candles regularly. In spite of this apparent correlation...homeowners experiencing discoloration problems have refused to consider the idea that burning of candles or other materials indoors could be a causal factor."

This study was designed to offer support to the conclusions of IAQ investigators by attempting to match or link "soot" found in five homes with the soot given off by the candles that were burned in those houses. Specifically the study involved the following:

- Identifying five houses that had streaking or sooting problems and in which homeowners reported candle burning.
- Conducting a thorough indoor air quality audit on each home and identifying all possible pollutant sources and pathways. Other parameters such as age of the home, style, airtightness and occupant lifestyle would be documented.
- Collecting samples of the soot from various locations as well as samples of the candles that were burned in the home.
- Analyzing the samples and collecting soot samples from burning the candles in a laboratory. The soot samples would be compared to see if common elements could be identified that would link the house soot samples with the laboratory candle soot.
- Interviewing the occupants to determine the history of candle burning and the sooting problem.
- Searching industry information to corroborate the likelihood of candles as a primary pollutant source.
- Identifying appropriate clean up and control procedures from industry sources.

Specific objectives were to:

- Match soot found in houses with soot from candles burned in the house.
- Identify an affordable sampling and testing method that could be used by IAQ investigators to isolate candle burning as the source of soot in a home.
- Identify cost effective clean up and control measures for soot problems.
- Provide findings that would support IAQ investigators in their efforts to explain the role of candle burning to homeowners with soot problems.

2. Candle Burning

A few notes on candle burning is appropriate to help focus on why the building industry is getting an increasing number of calls on this issue. According to the National Candle Association located in Washington, DC, U.S. candle consumer sales for 1999 are projected at $2.3 billion. Industry growth has been increasing 10-15% per year in the early nineties but is now at 20-30% per year. There are over 200 large manufacturers of candles and many more small craft producers. Typically a large producer will offer 1,000-2,000 varieties of candles. In the past colour and shape were the most important factors affecting sales, but recently the scent or fragrance has become an increasingly important element. Candle sales are seasonal, peaking at Christmas time. Candles are now used in 7 out of 10 U.S. homes. Canadian statistics are difficult to determine, as there isn't any association of Canadian candle manufacturers.

Currently there are no specific safety, material content or emission standards for candles in Canada other than the 1977 Health Canada ban on the sale of relight candles – candles which contain magnesium and when extinguished re-ignite spontaneously. Currently manufacturers are cooperating in the development of an ASTM standard for warning labels on burn hazards, and members of the National Candle Association in the U.S. have agreed voluntarily to stop production of lead wick candles.

"The National Candle Association" states "if candle wicks are kept trimmed and there is proper ventilation with no drafts, there should be no incomplete combustion and, therefore, no sooting from candles." Furthermore they indicate there should be no difference in the soot production from scented or unscented candles if they are used properly. "While it is the size of the wick that makes the most difference, unscented wax may burn more efficiently in general." However, IAQ investigators with experience in sooting problems suggest they find scented candles produce higher levels of soot.

"The National Association of Home Builders, Research Center" published a study in 1998, titled Carpet and Wall Discoloration in Homes. Candle burning and resulting soot were discussed at length. The study states " there are no test standards or publicly available data known to the Research Center comparing the soot production rates of different candles".

In a simple demonstration for this study two medium size candles with 1.5cm wicks were burned in a quiet, undisturbed 3m by 4m room for one hour. Using a MET 1 laser particle counter able to count particles of 0.3 microns and greater, it was found the total airbourne particulate count at a point 1m horizontally from the candles increased by over 30% over the one hour period.

In short, more and more homeowners are burning more and more candles each year and the style, shape and content of candles is highly variable. Furthermore, candle burning is usually seasonal, peaking through the darker winter months. There are no standards and little research available on soot emissions. These facts provide some insight as to why the building industry is seeing an increase in soot complaints and investigations.

3. Changes in Housing

In addition, there may be contributing factors stemming from changes in the building industry. Examples include:

- New higher efficiency furnaces deliver up to 20% more air than older furnaces. This may exaggerate airflow patterns in houses.

- More and more houses have central air conditioning and/or they keep the furnace fan running all year long. This increases the volume of air moving past carpets and wall cavities.

- New houses have gotten generally tighter with better windows and continuous air barriers and yet there are still many leakage points, specifically at floor assemblies, that allow air leakage in and out of homes – this may change airflow patterns in houses.

- Forced air heating duct designs typically have fewer ducted return air ducts in favour of large central return air grilles using wall cavities as the return plenum.

- Houses built early in large developments may be subjected to high construction dust loads for years.

- Lighter coloured carpets have become more acceptable as the carpet industry now offers better stain resistance.

4. Study Houses

The study relied on a network of builders, mechanical contractors, utility representatives and building scientists to identify potential study houses. Over a period of six months, approximately twelve houses were identified as having sooting or carpet streaking problems. Seven of these houses were seriously considered for the study, the others either didn't fit into scheduling constraints or occupants weren't interested in being involved. The occupants of the seven houses were interviewed by telephone to determine their willingness to participate, the nature of their problem or concern, and the history of candle burning in the home. One couple declined to participate as they were in a dispute with their builder over the problem, and felt the investigation might interfere with their claim. Another described minor discolouration, not black in colour, along carpet edges on exterior walls. They reported no candle burning and thus were not included in the study.

The five study houses included three townhouse units. All were middle units of their respective row house complex. The study houses were located in Guelph, Cambridge, London, Oakville and Grimsby, Ontario. There were many common elements to the homes including:

- All houses were new, less than 3 years old. Although this may be seen as a bias of the selection method for the houses, other articles on this topic, including CMHC's About Your House series, indicate the problem of streaking is most commonly associated with new houses. This could be due to increased expectations of new homeowners and new home warranties.

- Occupants of the houses were in all cases the first owners of each house.

- All houses had light coloured carpets.

- Each house had only two full time occupants. One house had a teenage child living at the house occasionally.

- All but one house had at least one dog or cat living in the house.

- All houses were built in accordance with the 1993 Ontario Building Code and had high efficiency direct vent gas furnaces, power vented water heaters and a principle exhaust fan ventilation system. Two houses also had direct vent gas fireplaces.

In all houses the occupants appeared to keep a neat and tidy household and all reported regular vacuuming, cleaning and general up keep of their homes. One house had two smokers living in the house. They reported they smoked only twice per day in the house, only ever in the kitchen with an exhaust fan running and the window open.

All occupants were very surprised candle burning was considered a possible source of the problem and most were slightly defensive when asked how often they burned candles. In all cases candles were reported as used regularly but not what they considered excessively. Chart 1 summarizes the occupants' characterization of their use of candles. In general, candles were burned in the evenings, often over dinner a couple of nights per week. Candles were primarily used in dining rooms, kitchens –while cooking dinner, bathrooms during bathing and on occasion in the master bedroom. The types of candles burned varied across the five houses and even within an individual house but included large 3 wick, deep well candles, small, coloured candles in glass wells, liquid paraffin candles to traditional taper candles. In one house a kerosene lamp was used on two or three occasions. Occupants reported the occasional use of scented candles. In all houses a variety of candles both burned and decorative were noticeably displayed.

A complete characterization of each house can be found in the Appendix on the Indoor Air Quality Audit Summary Sheets.

Chart 1

House #	Soot Description	Potential Combustion Sources	Other Dust Sources	Candle Burning
1	• Dark carpet streaking • Dark dust on return grilles and appliances • Gray dust on bathroom fan grille	• Smoking occupants • PV water heater • Candles	• Small dog • Storage of clothes • Busy highway • Many carpets • Lots of air leakage	• Uses 1 jar candle every 1 to 2 weeks
2	• Black carpet streaking • Black dust on lights, windows, inside cupboards, plastic surfaces	• DV gas furnace • PV water heater • Candles	• Large dog • Many carpets • New construction area	• Burns 2 large 3-wick candles 1 to 2 times a week for 2 - 3 hours
3	• Black smudges on window frames and plastics • Stained carpet edges • Gray dust on filter pads • Black film on kitchen counter top and cabinets	• DV gas furnace • PV water heater • Self cleaning gas range • DV Gas fireplace • Candles	• Many carpets • Old standard vacuum cleaner	• Burns many types of candles most evenings for short periods
4	• Dark & oily carpet streaking • Black smudges by exterior walls • Gray dust on cabinets, furnace fan and water tank	• DV gas furnace • PV water heater • Candles	• 2 cats and 1 small dog • basement renovation • Old & inefficient vacuum • Lots of air leakage	• Burns 2 scented votives about 1 to 2 times a week for 2 - 3 hours
5	• Black smudges on plastics • Carpet streaking • Black smudges on windows & frames • Pleated filters are very black	• DV gas furnace • PV water heater • DV gas fireplace • Candles	• 2 large fluffy cats • New construction area • Many carpets	• Burns 2 pillar scented candles about 2 nights a week for 1 - 2 hours.

5. Samples and Laboratory Testing

Samples were taken in accordance with the instructions provided by LEX Scientific Inc. of Guelph, Ontario – the laboratory partner in the study. In general, swab samples from hard surfaces were preferred. However, an effort was made to sample any material in the houses that showed signs of black staining, streaking or smudging. Materials sampled included furnace filters, carpet cuttings and insulation as well as swabs from window frames, appliance surfaces, light fixtures and cabinets.
One candle from each house, characterized as the most commonly used type of candle, was to be selected and sent to LEX.

LEX Scientific has a wide range of experience in microscopic evaluation of materials and material problems. A full listing of their services and expertise is included in the Appendix. In an effort to isolate a cost effective method for identifying soot from candles generally and individual candles specifically, LEX proposed to use a range of diagnostic techniques on each sample including:

- Microscopic analysis using a Zeiss Axioplan Universal Research Microscope
- Macroscopic analysis using a WILD Research Macroscope
- Analysis with an Hitachi S5400 Scanning Electron Microscope with a Noran Voyager Energy Dispersive X-ray analysis system (SEM/EDXA)
- Analysis using a Bruker Vector 22 Fourier Transform Infrared Spectrometer (FTIR) with microscopic attachment.

Furthermore LEX planned to burn the candles selected from each house and collect soot during the burn. The soot from the burn in the laboratory would be compared with the pollutants sampled from the houses.

Two houses were selected initially to start the study. An IAQ investigation was done on these houses and samples were submitted to LEX. Full analysis as listed above was conducted on the material samples, swabs and selected candles. The FTIR with microscope attachment and the SEM/EDXA tests were unsuccessful at identifying any elemental material other than carbon that could be used as a marker or identifier for specific candles. The microscopic investigation found, in general, the black material samples from house #2 as being consistent with candle residue as identified when the corresponding candle was burned. Material and swab samples from House #1 did not show any signs of materials from a combustion source.

A more complete discussion of findings will follow. However, the early testing indicated FTIR and SEM/EDXA analysis were not worthwhile. Rather it was decided further analysis would focus simply on microscopic identification of carbon elements consistent generally with products of combustion. Samples from house #3 and #5 were examined microscopically only. Two samples from House #4 showed significant quantities of black material that was identified as not being consistent with residue from a combustion source. Further analysis of this material was requested. A SEM/EDXA analysis was completed on these two samples. Results are discussed below.

6. General Investigation Notes

During the house investigations the following items were covered:

- Checking for proper operation and venting of all gas appliances. All gas appliances and vents were checked for any signs of soot, backdrafting or blockage. The investigation included checking (where applicable) of gas dryers, gas fireplaces, water heaters and furnaces. House #3 had a gas range and the range area was checked for signs of soot. The occupant of this house felt the soot might have appeared shortly after the first auto-cleaning cycle was done on her new range and stove. Since the stove was due for another cleaning, a small, cool glass collection plate was left 8" in front of the air vent for the stove during the two hour cleaning cycle. No noticeable or measurable accumulation of soot or other particles could be found on the plate after the cleaning cycle.

- Checking for proper operation and venting of exhaust appliances including bathroom fans, central vacuums and dryers.

- Simple pressure tests were taken across various rooms in houses. Using a digital manometer the pressure difference from rooms to adjoining hallways was noted with the room door closed and the furnace fan operating.

- Quick and simple depressurization testing (using a Minneapolis Blower Door) was done on the houses. The objective was to determine relative air tightness and to identify leakage paths along perimeter walls, around windows and floor headers. The testing did not include full quantitative analysis of leakage rates but rather subjective discovery of leakage potential and air movement.

- A moisture investigation to rule out the possibility of mold problems. None of the houses had experienced any significant wetting events such as leaks, floods or plumbing problems. None of the occupants reported excessive window condensation in winter months.

- A general IAQ investigation to list all potential indoor air quality pollutants.

7. Findings and Results

The laboratory results for each house can be found in the Appendix. A summary of the soot sampling and lab analysis is presented in Chart 2. At least one material and/or swab sample from three of the five houses was found to have elements consistent with candle soot or residue. As indicated previously, the laboratory results do not conclusively identify soot samples as having come from a candle. Rather the samples appear, when analyzed under a microscope, to be consistent with the soot samples taken from candles burned in the laboratory. Furthermore, in the two houses where sampling did not indicate candle residue, it may be possible candle soot is still part of the streaking problem but the samples taken did not include identifiable amounts of soot material.

The material samples included a wide array of components:

- Drywall particulates (listed as mineral type particulates in the lab reports but characterized as consistent with drywall compound by LEX).
- Cotton, fiberglass, cellulose and other fibers.
- Animal and human dander and hair.
- Pollen and mold spores

LEX subjectively assigned approximate percentages to the various components in each sample. Of great interest is that even samples which appeared to be very black – specifically swab samples from windows and other plastic components – were still determined to have a large percentage (40-50%) of mineral type particulates / drywall compound. In fact, although all but one of the samples were selected because they appeared black or at least very dark in the home, many samples contained either a low percentage of carbon soot or none at all. Clearly, other particulates in the houses are contributing to the appearance of a soot problem. There were many indications in each home of other significant dust sources: pets, construction materials, busy traffic areas, new and extensive carpets, storage of clothes. While candle soot may provide the colour for the stain or streaking, other pollutants constitute a significant volume of the particulate problems.

LEX was unsuccessful in determining a definitive "particle characterization" using spectroscopy that would conclusively identify soot samples as having come from candle burning. The first problem in achieving success would be to collect a sample free of contaminating substances. This proved to be difficult or impractical in this study and would likely be a barrier to future investigations. Variables in sampling techniques, experience of field investigators, surfaces where samples are taken from, age of the sample and other air pollutants in the home would affect the reliability of results. In fact in the 1998 study by the NAHB Research Center - "Carpet and Wall Discoloration in Homes"- it is stated "analysis experts suggest this method [spectroscopy] is not likely to achieve clear cut results". Furthermore the cost of such testing is approximately $250 per test. Conclusive results for one house would require a number of samples making the cost prohibitive to most homeowners or builders. The NAHB study concludes, "there is no single test or combination of tests that can be relied on to provide clear answers in every case". Also "testing to identify sources of soot has been inconclusive since the soot from different sources of combustion varies only in subtle ways." Carbon soot is formed from combustion or pyrolysis of organic compounds.

Occupants of House #2 and #3 reported freely their frequent use of candles. Both burned large triple wick scented candles for extended periods of time. These houses had the most visually pronounced streaking or staining problem with many surfaces and carpets having very black smudges or stains. The laboratory results for these houses showed most or all of the samples to have material consistent with candle residue or soot.

Occupants of House #1 and #4 reported they felt their candle use was unlikely a contributing factor because they didn't feel they burned candles long enough or often enough to cause a problem. A subjective comparison of streaking and staining patterns between these two houses and the other three noted the following:

- The staining in Houses #1 and #4 was mostly gray to black marks on carpets and furnace grilles, while the other houses had smudges on plastics, vinyl window frames, light fixtures and cabinets, in addition to the carpet staining

- The occupants in House #1 and #4 described their houses as very dusty and samples tested showed lots of fibres and drywall particulates. Specifically, the sample taken from the furnace fan in House #4 was the only sample taken in the study that did not appear black or dark in colour. This sample was noticeably gray. The only reason it was sampled was because of the obvious quantity on the fan blade and in and around the furnace.

- Houses #1 and #4 had obvious air leakage paths at floor headers, around wall penetrations and at window overhangs. Furthermore these houses were located near very busy traffic areas. Both occupants were finishing their basements.

As stated previously, additional testing was done on two samples from House #4. Swabs from the window and window frame appeared quite black and yet no material consistent with candle soot was found. A SEM/EDXA scan was done on each sample. The spectrum graph for these tests can be found in the Appendix. Of interest from the spectrum of Sample 1 was the presence of aluminium and titanium. These elements are commonly found in paint dust. That is, these samples are indicative of dust from painting and sanding activities – undoubtedly associated with renovation or construction activities in the home. This is consistent with activities in House #4. All other elements found are common elements in normal house dust.

Chart 2

House#	Laboratory Results Summary
1	• All four samples showed no signs of material consistent with candle soot. • Three of these samples were mostly made up of drywall compound.
2	• All four samples showed signs of candle soot material combined with a large amount of mineral type particulates such as sand, dirt, dust, and drywall compound. • Three of these samples were mostly carpet fibers.
3	• Two out of four samples showed a large percentage of candle soot material. • 50% of all four samples consisted of mineral type particulates such as sand, dirt, dust, and drywall compound.
4	• All 6 samples showed no signs of material consistent with candle soot. • Most of the samples showed large amounts of mineral particulates such as drywall compound.
5	• All 4 samples showed signs of candle soot material. • Three of the samples consisted of significant amounts of drywall compound materials.

8. Air Leakage and Room Pressure Testing

There is much information within the industry to support conclusions as to why stains, streaks and smudges appear on specific surfaces. A brief discussion of the pertinent issues is included below. It was not within the scope of this study to do a thorough investigation or evaluation of pollutant pathways or deposition patterns in these homes. However, simple testing of whole house leakage and room depressurization was completed and used to corroborate findings from the material sampling. The results of this testing are summarized as follows:

- All five houses had identifiable leakage paths to outside. Common leakage points included floor header assemblies, around exterior wall penetrations such as electrical outlets, plumbing vents, dryer vents, and furnace and water heater vents. In all houses ceiling penetrations such as bath fans and electrical fixtures had noticeable air leakage. In short, all of the houses demonstrated average to above average air leakage relative to typical new houses.

- Specifically in House #1there was a rough-in vent for a future downstairs bath fan that was only partially blocked with fiberglass insulation. This vent was very close to the dryer exhaust vent. In addition there was no air sealing done around the electrical service conduit and air conditioning refrigerant lines.

- Similarly, House #4 had at least three poorly sealed penetrations in the basement header. As well this house had two cantileavered window sections on the second floor that would be difficult to seal and demonstrated excessive air leakage.

- House #3 appeared to have the lowest air leakage rates. This was probably because it was the only single storey home.

- There was a slight but noticeable pressure difference across all rooms tested in all houses when the furnace fan was in operation. All of the houses had forced air heating systems with centralized return air ducts – at most two per floor, usually located in the hallways.

- Pressure differences across rooms ranged from 2 – 5 Pa. From this it can be concluded wall cavities connected to or used as the return air duct system will be under negative pressure.

9. Pollutant Pathways and Deposition Patterns

There are many airborne particulates in houses. Large particles settle out quickly in still air, smaller particles can stay suspended for extended periods, depending on air currents within the home. According to a study by John Spengler of Harvard School of Public Health, the tiniest particles such as viruses, of less than .01 micron in size, can take 10 days to settle 1 meter. Midsize particles, up to 20 microns, can take from 5 minutes to 10 hours to settle 1 meter, while large particles such as human hair and skin flakes, common pollens and observable dust will settle at a rate of 1meter / 5 seconds. Soot particles range from .03 – 5 microns in size. See Chart 3. The size of particles and the airflow movements within houses then determines where particles such as soot or candle residue may be deposited. Furthermore, candle soot particles and soot from other combustion sources are small enough that they may be affected by static charges or surface adhesion characteristics. For example, the polarity of plastic materials can create a large enough surface adhesion force to trap fine soot particles. Static charges also can attract small particles to solid surfaces.

The deposition patterns of soot within houses generally, and the study houses specifically, can be readily explained from common industry knowledge of airflow patterns, and filtration and surface attraction that effects materials within homes. For example:

- Poor air sealing details between the floor assembly and exterior perimeter walls on the second floor of houses, combined with the effect of warm air rising in houses due to stack effect throughout winter months, creates a consistent leakage of inside air to the outside. As this air pushes past the edge of carpets, the carpet fibres filter out dust and soot particles that are in the air. This may help explain why homeowners often first notice soot problems on second floor carpets near the end of winter.

- Similarly it is common practice to use the interior wall cavities of hallways as return air plenums for the furnace. While it is expected most air will be drawn from the return air grille, the entire wall cavity will be under a slight negative pressure and air may be drawn past carpets and under baseboard trim into the wall cavity. Again the air is being filtered by the carpets near interior walls, which are connected to furnace return systems. Vacuums are less effective or fail to clean the area closest to the walls unless a crevice/ perimeter tool is used.

- Subtle thermal currents are also at play in many houses. Cool air falls, warm air rises and fine soot particulates may be carried by these currents past surfaces or carpets. The particles may settle out or be captured by surface adhesion forces. Soot deposition on vinyl window frames is a good example of this combined affect. The cool window surface sets up a thermal current near the window and the polarity of the vinyl frames attracts fine soot particles as they float by.

As noted previously, staining in Houses #1 and #4 occurred primarily on carpets at both interior and exterior walls. This may indicate the predominant deposition mechanism within these homes was air leakage to or from outside and furnace fan operation.

Conversely, the fine soot particles found on window frames and plastic components in Houses #2, #3 and #5 were more likely the result of surface adhesion or static charge forces. Such depositions will occur most readily in very still air. Samples from these areas included fewer of the larger contaminants such as fibers or hairs than samples from carpets or furnace filters.

These deposition patterns may be useful in prescribing a sampling procedure specifically for fine soot particles. It would seem "cleaner" samples may be found on hard surfaces where subtle airflow patterns are at work.

Chart 3

Particle Settling Chart

Particles	Size	Settle Rate
• Human hair • Skin flakes • Observable dust (airborne) • Common pollens	10 microns (dust) to 150 microns (hair)	1 meter / 5 seconds
• Mite allergens • Common spores • Bacteria	1 micron (bacteria) to 20 microns (common spores)	1 meter / 5 minutes
• Cat dander • Tobacco smoke • Metal & organic fumes • Cell debris	0.01 microns (cell debris) to 0.9 microns (cat dander)	1 meter / 10 hours
• Viruses	Less than 0.01 micron	1 meter / 10 days

10. Control and Clean Up

There is consensus in the building science community on how to control sooting problems. The most practical approach is to follow the same procedures that is used for any general indoor air quality problem:

- Eliminate
- Isolate
- Filter
- Ventilate

Eliminating possible pollutant sources is the first priority. While this study focused on candle burning as a primary sooting source, any improperly operating combustion appliances in a home may be the source. IAQ investigators have found isolated problems with individual water heaters, fireplaces – even direct vent fireplaces, furnaces and dryers. Either through the process of elimination or extensive, and perhaps expensive testing, the contributing sources can be found. In the case of candles, the answer seems very simple, homeowners can be advised to stop burning candles for a short period of time and monitor the results. It should be noted, candle soot particles are very small and can stay suspended in air for long periods of time. Furthermore, accumulation of visible amounts of soot may take some time. For this reason, homeowners should be advised to avoid burning candles for a period of at least a month before trying to gauge results. This time period could be reduced if particle testing or air sampling were used to assist in the investigation. While homeowners in this study were surprised and defensive about the possibility for candles being a source of their problem, they were willing to accept a trial period of abstaining from candle burning.

This study identified other dust sources as being at least a contributing factor to the staining and streaking problems. The total dust load in houses should also be reduced. Suggestions include:

- Proper control and clean up during and after construction and renovation projects.
- Air sealing to avoid entry of dust from outside.
- More frequent use of more effective vacuum systems.
- Control of pet hair and dander.
- Careful selection of flooring, perhaps reconsidering the extensive use of carpets or at least choosing low pile, easy to clean carpets.

The appropriate operation of ventilation systems, now required by building codes across Canada, may also help reduce soot and dust accumulation in houses. Filtration strategies including more efficient central furnace filters and portable room filters will help reduce airborne dust. Filtration strategies must recognize soot particles are very small and only air filters capable of capturing small particles will be of interest. Such fine particle filters are often too restrictive on airflow to install on central furnace systems.

Other control measures would include strategies for controlling the various soot deposition mechanisms. For example, air sealing under baseboards and at floor header locations will reduce air leakage and thereby reduce soot deposits at carpet edges. Similarly, properly air sealing wall cavities that are part of the furnace return air system will reduce carpet streaking at interior walls. Better insulation to avoid thermal bridges in walls and using warmer window technology will reduce thermal currents and surface adhesion forces to reduce "ghosting" of wall studs and window frames.

Most of the control measures suitable for avoiding sooting problems are the same as those promoted for improving indoor air quality, energy efficiency and general occupant comfort.

Clean up of existing soot problems can be very frustrating for homeowners. Carbon soot can be quite greasy or oily and does not wash off painted surfaces or drywall very easily. Repainting may be the only answer. Even more difficult is the clean up of carpets. Bulletins from *"The Carpet and Rug Institute"* (CRI) in Georgia, the International Society of Cleaning Technicians (ISST) also from Georgia and the Floorcovering Institute of Ontario (FIO) indicate the following:

- Most carpets today are made from synthetic fibers that are petroleum derivatives. These fibers or the dye in the fibers may be oxidized or chemically attacked by the hydrocarbon soot particles.

- The accumulating soot may combine with other airborne particulates and other dust in the carpets and sit for months in the carpet before being cleaned. This means the cleaning effort may recall a multi-step process to address each type of pollutant present.

- The particle sizes of soot may be resistant to suspension by detergent action.

- Success in cleaning will vary, but in all cases a qualified cleaning technician should be consulted. The CRI offers guidelines for cleaning professionals. *"The Floorcovering Institute of Ontario (FIO)"* in Mississauga suggests cleaning efforts should focus on improving the appearance, "as complete removal is rare".

- The CRI and other flooring organizations such as the (FIO) are quick to point out that this is not a carpet problem but rather related directly to indoor conditions such as airflow patterns and pollutants in the air.

- The Spring, 1995 edition of the CRI publication Industry in Depth points out "carpet manufacturers have also learned that carpet actually traps many airborne particulate contaminants and holds them until they can be properly extracted by effective vacuuming and other cleaning methods."

In general, proper cleaning procedures include:

- Vigorous and repeated dry soil removal with an effective vacuum with appropriate attachments.

- Pre-spray with a high pH solvent action cleaner to dissolve oils, gentle agitation, and a fifteen-minute dwell time.

- Extraction with a detergent based cleaner and hot water.

- Rinse with very hot water and a mild solution of emulsifier.

11. Summary and Recommendations

The reported incidence of staining, streaking, sooting of carpets, walls and furnishings in houses is becoming more common. The problem has become very prevalent for new homebuilders. Reasons for this increase may be:

- Higher total dust loads in houses generally and new houses specifically.
- Dramatic rise in the sale and use of candles in houses compounded by the profusion of different waxes, fragrances and styles of candles that may affect soot production.
- The preference for lighter coloured carpets – lighter carpets have become more popular as the carpet industry improved the stain resistance and cleanability of carpets.
- A shift in the general airflow patterns in houses - new higher efficiency furnaces may move up to 20% more air; air sealing in homes that makes houses tighter overall but leaves some key areas prone to air leakage (specifically floor assemblies); the increased use of forced air mechanical cooling systems; and variables in the design and construction of duct work systems in houses.
- Higher expectations of new home buyers and new home warranties.

Much attention has been focused on candles as a primary pollutant. This study showed it is difficult and probably impractical to rely on laboratory testing to positively identify the source of soot, specifically with respect to candles. However, simple microscopic analysis can indicate generally whether sampled pollutants are from a combustion source consistent with candles. From there, standard diagnostic techniques such as isolating potential sources can be used. Consistent with other indoor air quality problems, homeowners and builders would be advised to spend less time and money on identifying specific pollutants and more on eliminating, controlling and cleaning up known potential sources.

If sampling of soot is indicated or desired, the most reliable sampling sites are likely to be hard surfaces that are subject to subtle airflow patterns – vinyl window frames, exterior walls, or plastic cabinet components. Surfaces or materials that are subject to strong airflow forces such as forced air furnaces or major air leakage pathways are more likely to collect a wider array and greater quantities of dust, fibres, hair and other pollutants. This makes identification of carbon soot more difficult. Clearly much of the volume of what appears to be black staining or streaking is often actually common household dust coloured by smaller amounts of soot.

Two of the study houses with carpet streaking problems were not found to have candle soot in the test samples taken. In these houses the streaking was limited to carpets, furnace grilles and filters. The major pollutant found was drywall compound that under normal circumstances appears gray in colour. In the houses where candle soot was identified, the small soot particles were found on window frames, inside cabinets, on light fixtures in addition to the carpet streaking. Investigators may be able to use these subtle deposition differences to help identify the primary pollutant sources.

Clean up of streaking problems, specifically on carpets, is difficult and rarely completely successful. While it is important to attempt early, rigorous cleaning of affected areas, homeowners are advised by the carpet industry that improvement in appearance may be the best, expected outcome.

Given the poor success rate in clean ups, avoidance and control of contributing factors should be the focus of homeowners and builders. The following recommendations should reduce the risk of streaking and sooting. Future industry research may identify more specific causes and solutions.

Homeowners should:

- Avoid or restrict the use of candles in houses.
- Use candles with properly trimmed wicks, in properly ventilated conditions and as per manufacturer's instructions. Avoid or limit use of scented candles. The National Candle Association website gives specific information on how to choose and burn candles so as to avoid soot problems.
- Have combustion appliances in the home checked regularly for proper operation and venting effectiveness.
- Keep a clean house generally and vacuum carpets regularly with an effective vacuum – central vacuums vented outside or HEPA grade filters are the best options. Use perimeter tool for wall edges.
- Never idle vehicles in an attached garage and ensure the garage is properly air sealed from the house.
- Eliminate or control other dust sources – proper clean up of renovation projects, reduce storage of wood, paper and fabric products, control access of pets to certain areas of the house.
- Purchase and maintain better filters for the forced air system.

Builders should:

- Build tighter houses generally and specifically ensure air leakage pathways at floor header assemblies are well sealed.

- Use insulation techniques and wall details that minimize thermal bridging and cold spots.

- Ensure garages are air sealed from the home and any ductwork running through the garage is tightly sealed.

- Ensure all combustion appliances are properly installed and vented. Avoid standing pilot appliances and encourage direct vent, sealed combustion appliances.

- Clean houses thoroughly after the drywall and taping stage to eliminate drywall and other construction dust.

- Ensure forced air ducts are sealed during construction and /or cleaned thoroughly before carpets and other flooring are installed.

- Offer upgraded filters for forced air systems.

- Offer darker carpet colours or educate homeowners that streaking problems are more visible with light carpets.

Appendix

House #: 1

House Address: Grimsby, Ontario

Description of House:

Two storey, townhouse – middle unit of row houses, vinyl siding home built in fall of 1997.
Light beige carpets throughout much of the main floor and second floor.
Had two basement floods in spring of 1998, anything that got wet was thrown out.
No attached garage, cars parked out front.
Part of basement is being finished by occupants.
Lots of signs of air leakage in header areas, downstairs bath fan vent roughin has been left open and is beside dryer vent. Overall leakage was average to above leakage as compared to new homes generally

Description of "Soot" Problem:

Problem first noticed in winter of 1998/1999, dark streaking on perimeter of carpets on inside walls.
Lots of gray or black dust accumulation on furnace return grilles, behind fridge, and on appliances.
Carpets under doorways have pronounced dark staining – both upstairs and main floor.
No soot or black in or around water heater or air handler.
Standard disposable filters in furnace are replaced monthly and don't get very black.
Lots of gray dust on bathroom fan grille.
Odd shaped droplet marks – dark in colour – on kitchen walls.

Combustion Sources:

Power vent water heater with electronic ignition, heating is provided by combo air handler.
Electric dryer venting well – no sign of any black in vent.
Busy highway nearby.
Candles – one candle burned many evenings for short periods, use up about one jar candle every week or two, always burned in the kitchen / eating area.
On rare occasions another small candle is burned in the living room.
Both occupants smoke but only twice per day in the house and window is left open while smoking.

Other Dust Sources and Notes:

One small dog.
Outside there is a very busy highway and a rail line.
Lots of carpets throughout the house.
Range hood used when cooking, bath fan (principle fan) used 1 hour per day.
Lots of storage of clothes and other items in the basement.
Ongoing project to finish part of the basement.
Older vacuum used, seemed to perform poorly in picking up dust.

Summary of Laboratory Testing:

Four samples, two swabs from hard surfaces that appeared to have black or dark dust and two material samples.
None showed signs of material consistent with candle soot.
Three samples were made up mostly of drywall compound or texture coat.

House #: 2

House Address: Guelph, Ontario

Description of House:

Two storey, brick and vinyl siding home built in summer of 1997 with attached garage.
Light gray/white carpets throughout much of the main floor and second floor.
No moisture problems other than occasional window condensation. .
Basement is not finished but feels warm and dry.
House had common air leakage points, headers, electrical outlets, under baseboards on upper storey.
Overall house leakage was average when compared to typical new houses

Description of "Soot" Problem:

Problem first noticed after first winter, black streaking on perimeter of carpets and carpets on stairs.
Now has accumulated on lights, windows, inside kitchen cupboards and on plastic surfaces.
Most pronounced carpet problems are on main floor.
No soot or black in furnace or water heater.
Standard disposable filters in furnace are replaced monthly and don't look very black.

Combustion Sources:

Direct vent furnace, sealed combustion, electronic ignition.
Power vent water heater with electronic ignition.
Gas dryer venting well – no sign of any black in vent.
Attached garage – car never warmed up in garage.
Candles – burned on average once or twice per week for 2-3 hours, 2 large triple wick candles, other smaller candles, burned in kitchen and main floor family room.

Other Dust Sources and Notes:

One large dog.
Outside is a new construction area and there are signs of soil dust on window exteriors.
Central vacuum vented to the garage – plastic pipes have black smudges on them.
Lots of carpets throughout the house.
Range hood and bath fan (principle fan) used only occasionally.
Ducts have been cleaned once and furnace was checked.

Summary of Laboratory Testing:

Four samples, all swabs from hard surfaces as they appeared to have the most black material.
All showed signs of candle residue as well as common mineral type particulates such as sand, dirt, road dust, and drywall compound.
Three samples show many miscellaneous fibers – most likely carpet fibers.

House #: 3

House Address: Cambridge, Ontario

Description of House:

New one storey, townhouse with walkout basement – middle unit of row houses, brick and vinyl siding.
Light gray/white carpets throughout much of the main floor and basement, basement is finished space
Never had any moisture problems. Uses an air freshener regularly
Attached garage – car never warmed up in the garage .
House appears to be relatively tight with not too many signs of air leakage in the home, tighter than average new homes.

Description of "Soot" Problem:

Problem first noted in winter of 1999, dark smudges on plastic / vinyl components in bathroom, office.
Window frames in the upstairs office have black smudges; carpet edges in hallway are stained.
Filter pads installed on return air grille get a gray/black dust or film on them.
No soot or black in or around water heater, furnace or dryer or any of the vents .
Pleated media disposable filters in furnace are replaced monthly and have been very black.
Counter top and cabinets in kitchen get a black film.

Combustion Sources:

Direct vent, sealed combustion furnace was checked by installer.
Power vent water heater with electronic ignition, was replaced after it overheated once.
Gas dryer venting well – no sign of any black in vent.
Direct vent Gas fireplace in basement was checked and no signs of soot.
Gas range with self cleaning option – this was tested once with no sign of soot.
Candles – many different types of candles used, burned many evenings for short periods, burned in the kitchen, living room, master bedroom, bathroom and downstairs family room.
Candles range from triple wick large to small liquid paraffin to standard taper candles.
Occupant burned a kerosene lantern on two occasions.
Attached garage but car never warmed up in garage.

Other Dust Sources and Notes:

Lots of carpets throughout the house.
Range hood not used very often, bath fan (principle fan) left on much of the day.
A standard older vacuum cleaner is used.

Summary of Laboratory Testing:

Four samples, 2 swabs from hard surfaces, a furnace filter and one of the common candles.
Two of three samples showed a significant percentage of material consistent with candle soot.
50% of all samples was mineral type particulates consistent with lint, sand, dust or drywall compound.
One large scented triple wick candle was burned in the laboratory. Large amount of soot was collected in a short period of time from the candle burn.
Furnace filter had been changed within a month and appeared very black.

House #: 4

House Address: London, Ontario

Description of House:

Condominium ownership, middle unit of row house complex, two storey, brick and vinyl siding exterior.
Many tricky window overhangs and brick ledges creates air sealing problems, lots of air leakage, higher than typical new homes.
Moved into this new unit in late spring 1997.
House is in a valley below a busy traffic area, no garages, all cars parked out in front of units.
Basement is being finished by occupants, never had any water problems.
Carpet throughout most of the home – mostly light coloured, carpet in basement is a dark green colour.
Direct vent furnace and water heater, electric fireplace and electric range.

Description of "Soot" Problem:

First noticed after first winter, 1998, vinyl floor in kitchen and carpet edges upstairs were very black.
Worst on second floor along exterior perimeter walls and some interior walls, carpet on stairs was bad but has been removed, basement carpet has no problem.
Main floor first noticed last winter, black on carpet beside the powder room, carpet by furnace supply vents are darker, return air grilles are relatively clean, carpet at top of stairs has noticeable streaking.
Soot was first described as very black and oily, not as bad now, more gray or dark gray.
Gray dust accumulates on cabinets; gray dust was noticeable on furnace fan, at top of water tank.

Combustion Sources:

Direct Vent gas furnace, checked twice – there was some type of problem with the furnace but they were told it was unrelated to the soot – although timing of first noticing soot was shortly after furnace problem.
Power vented water heater.
No other combustion appliances in the house – outdoor gas barbeque, cars parked 6 meters away.
Candles – burned mostly in winter, sometimes scented, average 1-2 times per week for 2-3 hours.
Often burns 2 candles at a time, mostly in living room or dining area, in master bedroom.
Mostly small diameter candles.

Other Dust Sources and Notes:

Two cats and recently one small dog.
Ongoing construction project in the basement.
Lots of air leakage around basement header area.
Bath fan used when showering only.
Fresh air intake installed into return air last winter.
Carpets have been cleaned twice, unable to remove streaking.
An older, inefficient vacuum is used.

Summary of Laboratory Testing:

Six samples, 2 material samples and 4 swabs from hard surfaces.
All samples, except one from furnace fan blade, appeared to be quite black.
No evidence of material consistent with candle soot or residue.
Most samples showed large amounts of mineral particulates consistent with drywall compound.
Second set of tests conducted on black material from window and window frame. This material showed mostly common elements – carbon, silica, calcium – however, presence of titanium is indicative of paint dust – probably related to construction or renovation.

House #: 5

House Address: Oakville, Ontario

Description of House:

Two storey, all brick home built in 1996.
Light beige carpets throughout much of the main floor and second floor.
One small, brief foundation leak, fixed immediately.
Attached garage and cold storage room.
Basement is not finished but feels warm and dry.
House appears to have average air leakage, air leakage from around headers, electrical outlets etc.

Description of "Soot" Problem:

Problem first noticed a year ago, black smudges on plastic cutlery tray and plastic bowls in kitchen.
Problem is more pronounced now, along edges of carpets upstairs, in bedrooms used the least.
Most pronounced carpet problems are on inside walls of bedrooms.
Black on windows and window frames.
Some black on plastic items in basement.
No soot or black in furnace, water heater or gas fireplace vents, draft hoods or on the appliances.
Pleated furnace filters, changed once per month, very black.

Combustion Sources:

Direct vent furnace, not sealed combustion, electronic ignition.
Power vent water heater with electronic ignition.
Direct vent gas fireplace, with standing pilot – flame is mostly blue.
Attached garage – car never warmed up in garage.
Candles – burned mostly in winter, average two nights per week for 1-2 hours, 2 candles on average mostly deep-well, scented candles burned in kitchen and dining room, sometimes in upstairs bathroom.

Other Dust Sources and Notes:

Two large fluffy cats.
Outside is a new construction area and there are signs of red soil dust on window exteriors.
Central vacuum vented to the garage.
New carpets throughout the house.
Range hood used when cooking, bath fan (principle fan) used only when showering.
Carpets have been cleaned twice – once per year, ducts cleaned once.
Two bedrooms windows are left slightly open much of the time.

Summary of Laboratory Testing:

Five samples, three swabs from hard surfaces, a furnace filter and a sample from carpets, which did not yield sufficient material for analysis.
All analyzed samples show evidence of candle residue.
A significant portion of at least three samples was material consistent with drywall compound.

Methods

The samples were examined using a Zeiss Axioplan Universal Research Microscope and a WILD Research Macroscope. Photomicrographs were acquired using a Contax RTS II 35mm camera with attachment to the microscopes.

Results

The samples were observed to contain (with approximate percent concentrations):

Sample 1: Carpet

• Mineral type particulate	>90%

Sample 2: Insulation from Header in Basement

• Fiberglass fibers	80-90%
• Cellulose fibers	1-5%
• Mineral type particulate	1-5%

Sample 3: Wall Swab (see Figure 1.1)

• Mineral type particulate	60-70%
• Multicolored fibers	5-10%
• Starch	1-5%
• Pollen (assorted)	1-5%
• Cellulose fibers	1-5%
• Tree parts	trace
• Yeast	trace

Sample 4: Swab from Top of Fridge (See Figure 1.2)

• Cotton fibers – multi-coloured	20-30%
• Mineral type particulate	40-50%
• Animal hair	5-10%
• Pollen	5%
• Mold	1-5%

In the above samples the mineral type particulate was consistent with surfacing material such as drywall compound or texture coat.

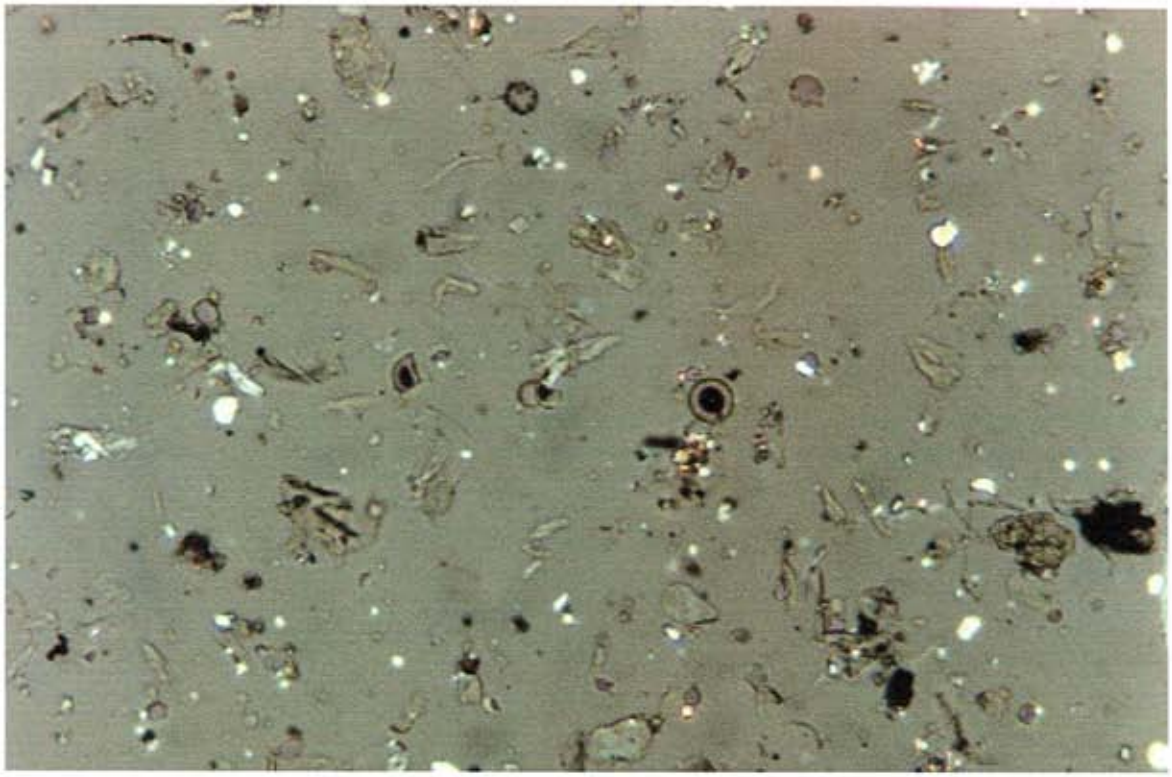

Figure 1.2: Photomicrograph of House#1 Wall Swab

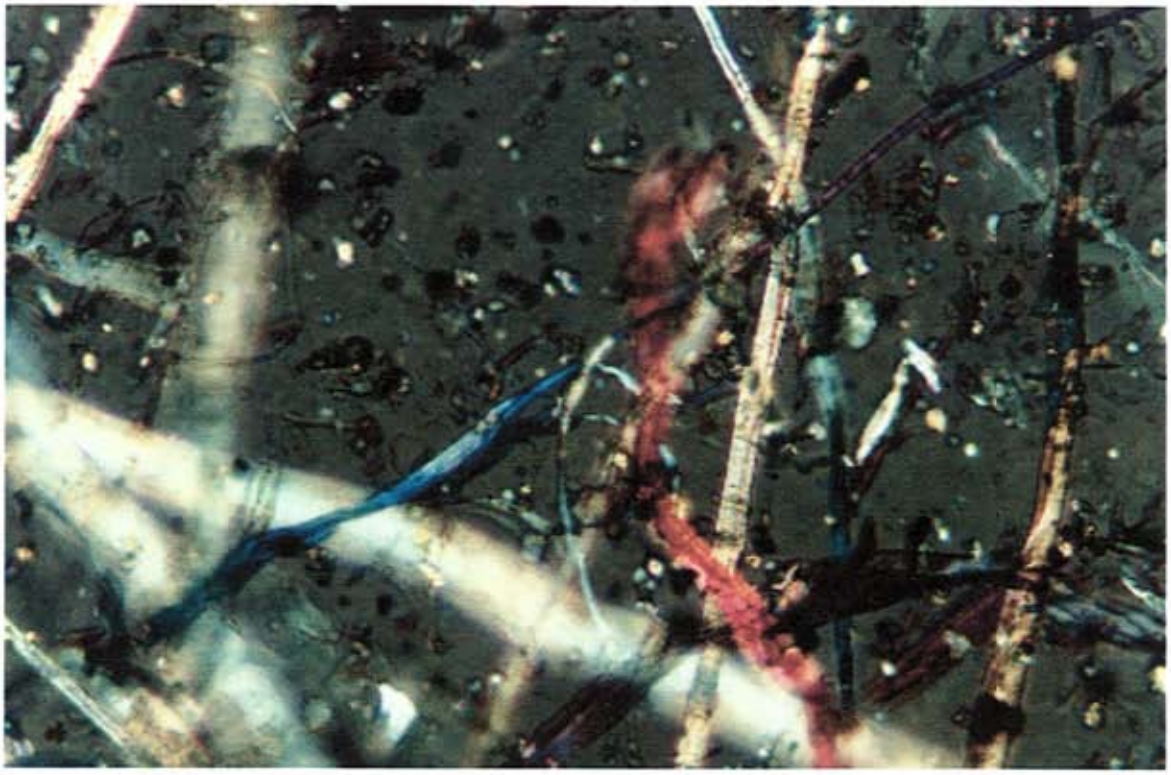

Figure 1.2: Photomicrograph of House#1 Top of Fridge Swab

Methods

The samples were examined using a Zeiss Axioplan Universal Research Microscope and a WILD Research Macroscope.

Results

The results of microscopic examination are as follows (with approximate percentages):

Sample 1: Kitchen Cabinets- Swab

• Miscellaneous fibers	50-60%
• Animal and human hair	1-5%
• Mineral type particulate	20-30%
• Black material consistent with candle residue or soot	5-10%

Sample 2: Window Frame - Swab

• Mineral type particulate	40-50%
• Black material consistent with candle residue or soot	50-60%

Sample 3: Light Fixture - Swab

• Miscellaneous fibers	10-20%
• Mineral type particulate	30-40%
• Black material consistent with candle residue or soot	40-50%

Sample 4: Furnace Return Air Grille - Swab

• Miscellaneous fibers	30-40%
• Animal hair	5-10%
• Mineral type particulate	30-40%
• Black material consistent with candle residue or soot	10-20%

In the above samples the mineral type particulate was either consistent with surfacing material such as drywall compound or consistent with common atmospheric dust or dirt.

Methods

The samples were examined using Zeiss Axioplan Universal Research Microscope and a WILD Research Macroscope. Photomicrographs were acquired using a Contax RTS II 35mm camera with attachment to the microscopes.

Results

The samples were observed to contain with approximate percent concentrations:

Sample 1: Window Frame Swab- (see Figure 3.1)

- Mineral type particulate 50 %
- Fiberglass 5%
- White material (paint?) 10%
- Black material consistent with candle residue or soot 30%

Sample 2: Toilet Tank Swab - (see Figure 3.2)

- Mineral type particulate 50%
- Multicolored fibers (cotton and cellulose) 40%
- Hair (human and animal) 5%
- Starch 5%

Sample 3: Filter From Furnace - (see Figure 3.3)

- Mineral type particulate 40%
- Black material consistent with candle residue or soot 30%
- Multi-coloured fibers (cotton and cellulose) 20%
- Starch 5%
- Hair (human and animal) 5%

Sample 4: Large White 3-wick candle burned in the Laboratory- (see Figure 3.4)

- Fine candle residue or soot

In the above samples the mineral type particulate may be common elements of house dust, sand, road dust or drywall compound.

Figure 3.1: Photomicrograph of House#3 Window Frame Swab

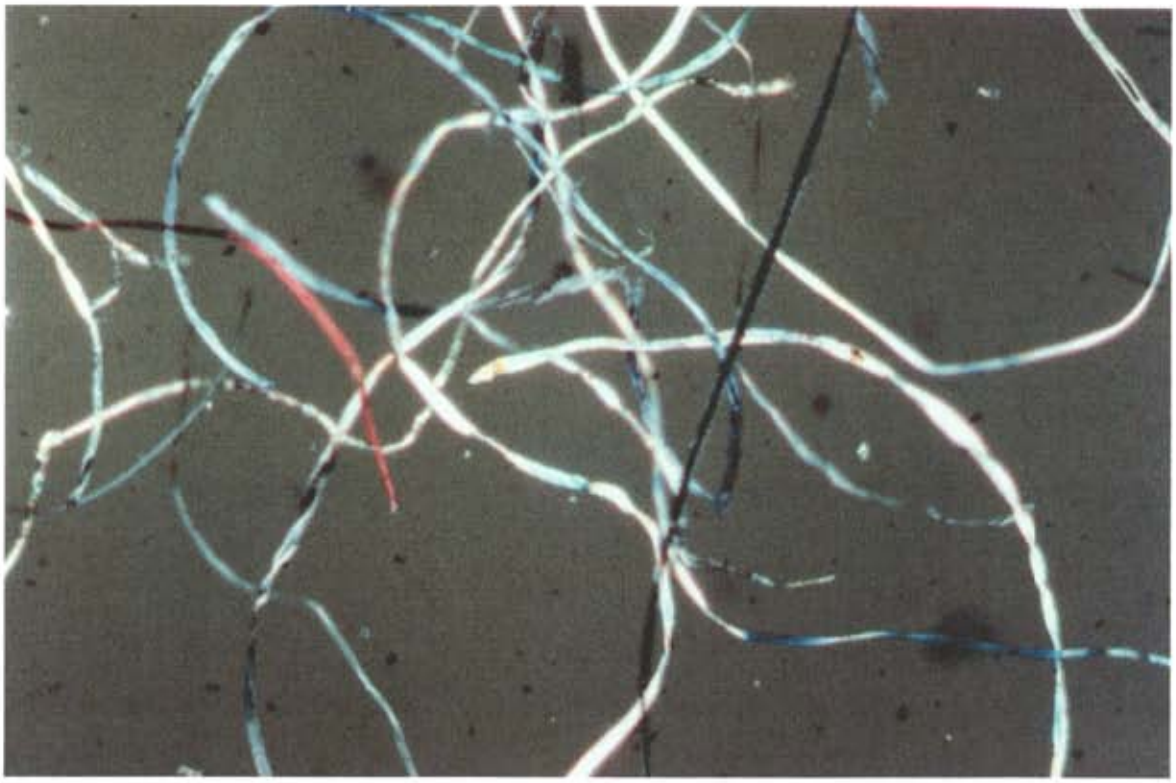

Figure 3.2: Photomicrograph of House#3 Toilet Tank Swab

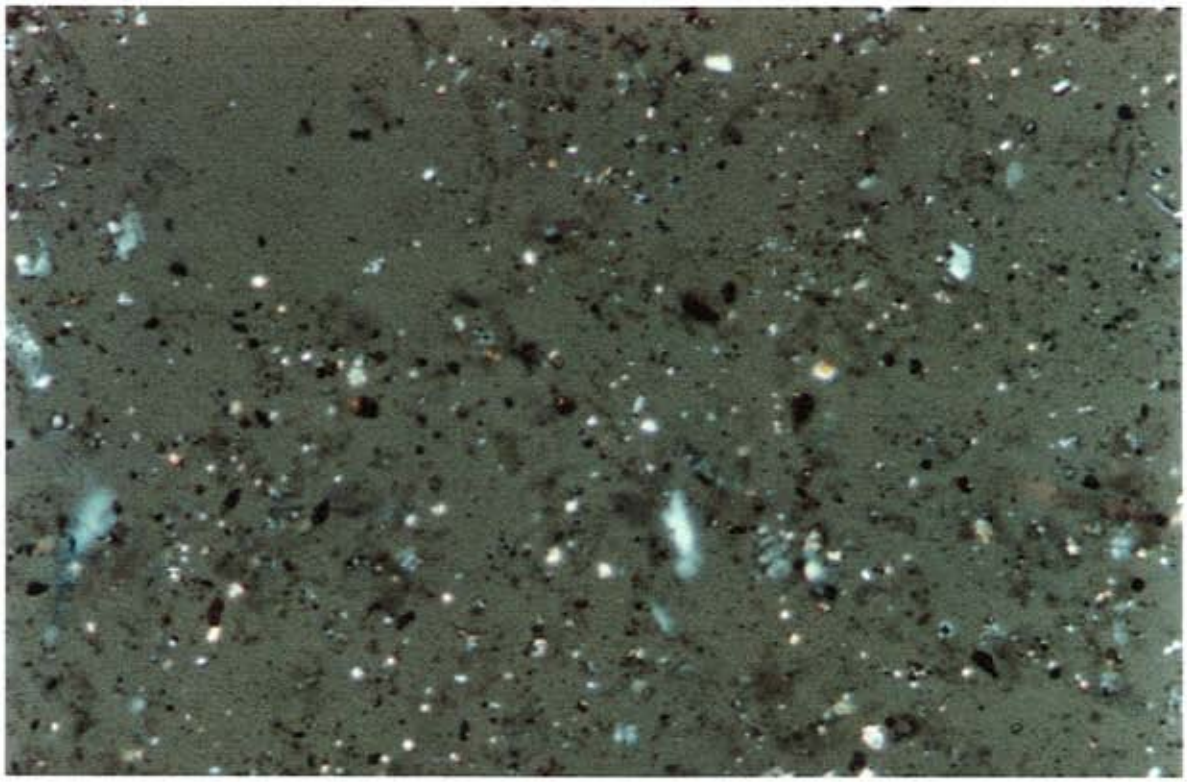

Figure 3.3: Photomicrograph of House#3 Furhace Filter

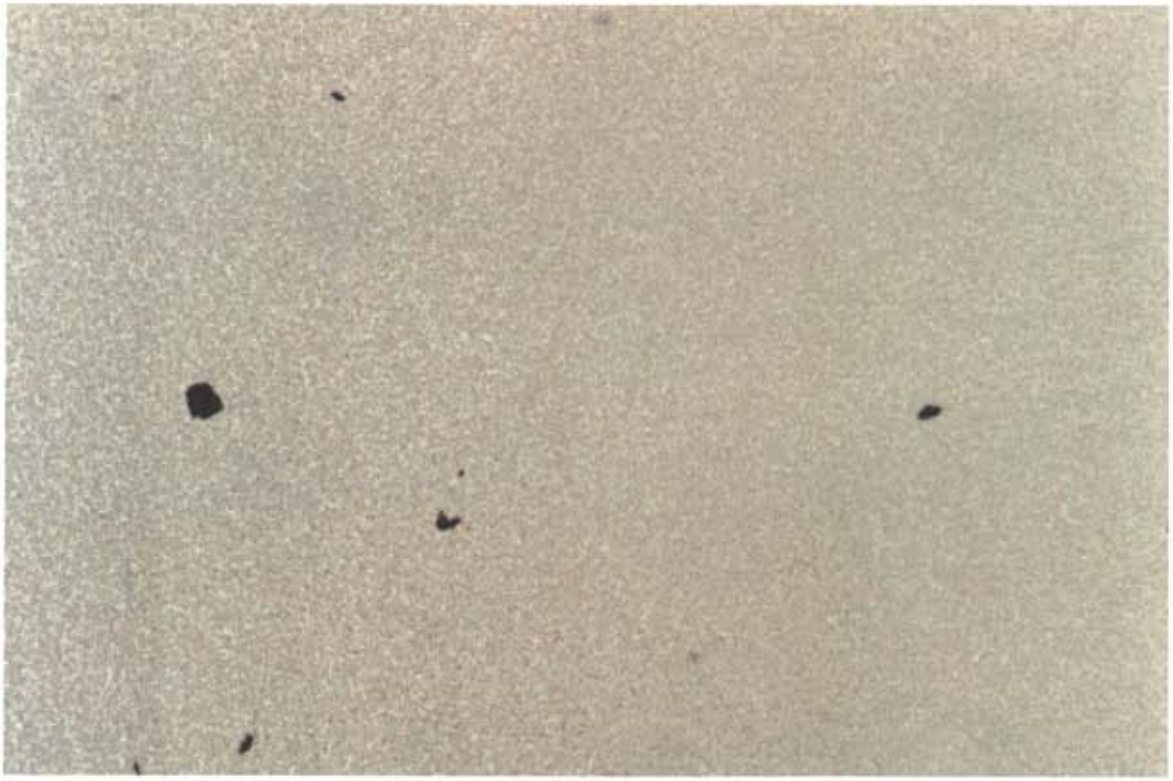

Figure 3.4: Photomicrograph of House#3 White 3 Wick Candle

Methods

The samples were examined using a Zeiss Axioplan Universal Research Microscope and a WILD Research Macroscope. Selected samples were analyzed using Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (SEM/EDXA).

Results

The samples were examined microscopically and observed to contain (with approximate percent concentrations):

Sample 1: Window Frame – swab (Figure 4.1)

- Mineral type particulate 50%
- Black unidentified material (not consistent with products of combustion) 50%

Sample 2: Front Upstairs Window – swab (Figure 4.2)

- Black unidentified material (not consistent with products of combustion) 100%

Sample 3: Furnace Fan Blade – swab

- Mineral type particulate 100%

Sample 4: Water Heater – swab

- Mineral type particulate 100%

Sample 5: Header Insulation - sample

- Fiberglass fibers 10%
- Cellulose fibers 30%
- Mineral type particulate 60%

Sample 6: Carpet- sample

- Mineral type particulate 90%
- Hair (animal) 10%

In the above samples the mineral type particulate was consistent with surfacing material such as drywall compound or texture coat.

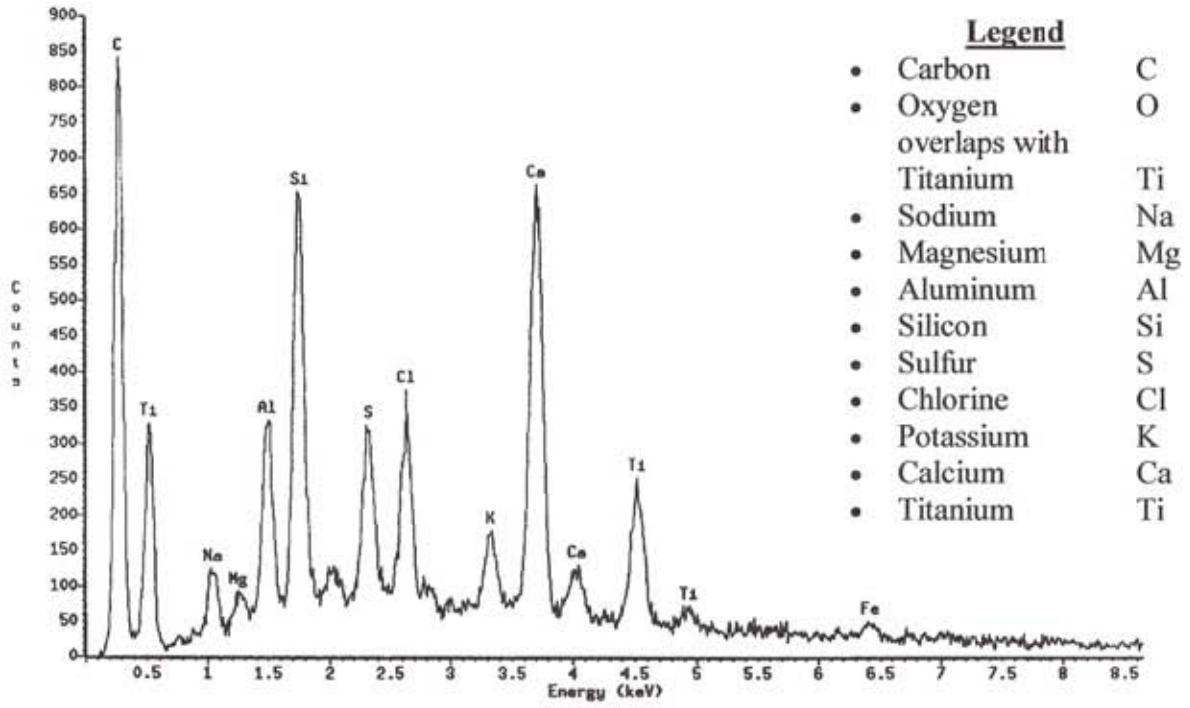

Figure 4.1 – SPECTRUM of House#4 Window Frame Swab

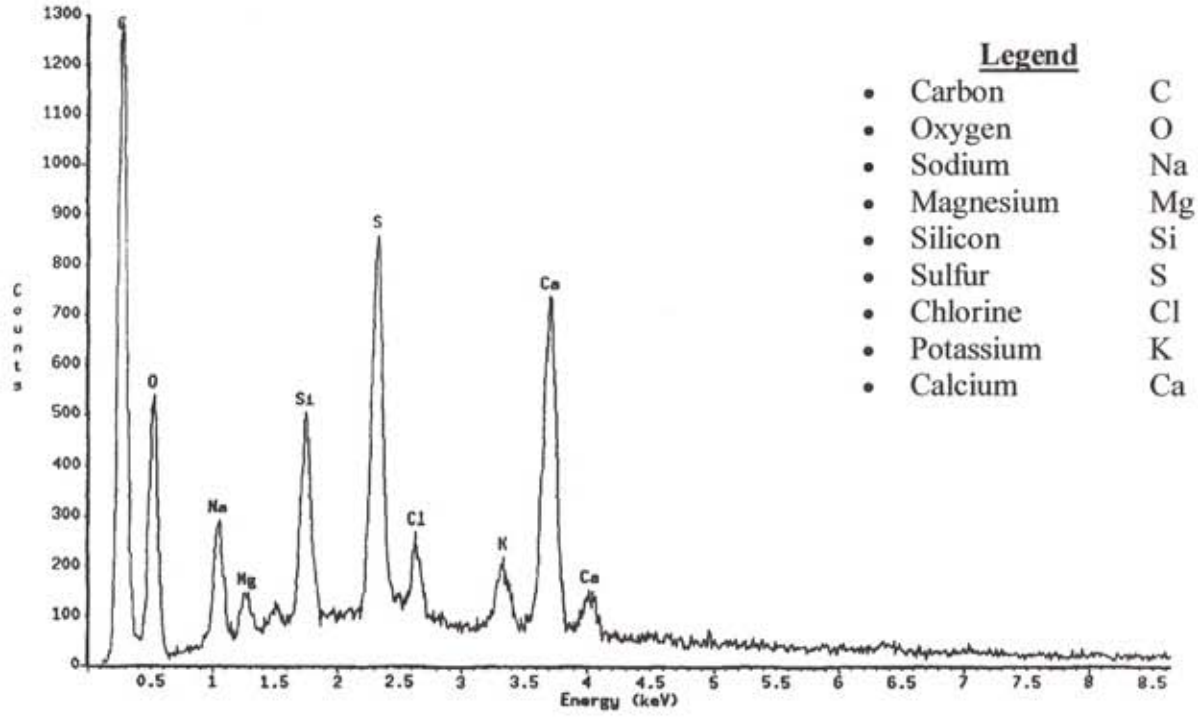

Figure 4.2 – SPECTRUM of House#4 Front Stair Window Swab

Methods

The samples were examined using a Zeiss Axioplan Universal Research Microscope and a WILD Research Macroscope.

Results

The results of microscopic examination are as follows:

Sample 1: 16x24 Duststop Filter

• Miscellaneous fibers	50-60%
• Hair	1-5%
• Mineral type particulate	20-30%
• Black material consistent with candle residue or soot	5-10%

Sample 2: Window Frame Back Bedroom - Swab

• Mineral type particulate	10-20%
• Black material consistent with candle residue or soot	80-90%

Sample 3: Carpet Fibers Back Bedroom

- Not enough material on carpet fibers for identification

Sample 4: Furnace Draft Hood – Swab

• Mineral type particulate	>90%
• Black material consistent with candle residue or soot	1-5%

Sample 5: Inside Drawer Kitchen - Swab

• Mineral type particulate	40-50%
• Mold	1-5%
• Black material consistent with candle residue or soot	50-60%

In the above samples the mineral type particulate was consistent with surfacing material such as drywall compound or texture coat.

Sample Pictures

References

References

LEX Scientific Inc.
2 Quebec Street, Suite 204
Guelph, ON, N1H 2T3
Tel: 800-824-7082
Fax: 519-824-5784

LEX Scientific offers a diverse range of services backed with a distinguished array of equipment and a diversity of experts with decades of experience. LEX's experience with Industrial Health ensures Health and Safety Professionals can access prompt and reliable solutions to their specific issues. Utilizing their expertise, LEX professionals provide working world solutions for industrial challenges.

While most of our clients require our services in Southern Ontario, LEX has served clients in California and performed on-site analysis in as remote areas the Magnetic North Pole.

LEX Scientific Inc. provides a comprehensive range of Laboratory Services relevant to your needs including analysis for:

- Asbestos
- Mold
- Radon
- UFFI
- Lead
- Air Contaminants
- Particle Size & Identification

LEX Scientific's distinguished mix of analytical equipment, including such tools as ultramicroscopic detection devices and computerized image analysis, make our services unique. Our vast problem solving capabilities combined with our unique equipment enable cost effective solutions to problems that seem to have no solution.

Accreditation:

- Accredited by the NIST NVLAP for Asbestos Analysis.
- Participant in the AIHA – EMPAT program *(Environmental Microbiological Proficiency Analytical Testing)*
- Participant in the Canadian Association for Environment Analytical Laboratories (CAEAL) program.
- Audited for Good Laboratory Practices (GLP) for pharmaceutical analysis.

References

1. Alberta Lung Association, ***Aromatic Candles: Potential Health Hazards?***, Second Wind December 1999. www.lung.ca

2. Building Science Corp., ***Black Stains on Carpets and Ghosting of Framing,*** News & Views, Westford, Mass.

3. Floorcovering Institute of Ontario, ***Carpet Care Tips: Filtration Soiling,*** www.flooringinstitute.com

4. Health Canada, Health Protection Branch, Product Safety, ***Candle Information Bulletin for Dealers***

5. Millette, James & Few, Pronda; MVA Inc., ***Indoor Carbon Soot Particles,*** Microscope Vol 46.4 201-206, 1998

6. Morgan, Ray; International Society of Cleaning Technicians(ISCT), ***Filtration Soiling,*** Technical Bulletin, September 1994

7. National Association of Home Builders(NAHB) Research Center, ***Carpet and Wall Discoloration in Homes***, November 1998

8. National Candle Association, ***Candle Industry Facts,*** Washington, DC. www.candles.org

9. The Carpet & Rug Institute, ***Carpet: The Environmentally Responsible Floorcovering of Choice,*** Industry in Depth, Spring1995

10. The Carpet & Rug Institute, ***Filtration Soiling,*** CRI Technical Bulletin, Dalton Georgia 1997
11. Rehel, Mike; Carpet Specialist, ***Soil: Filtration Lines,*** Technical Services Division, Crossley Carpets

12. Vigil, Frank; Advanced Building Corp., ***Black Stains in Houses: Soot, Dust, or Ghosts?***, Raleigh North Carolina 1999. www.homeenergy.org

13. Wittkamp,Bob; Textile Cleaning Institute, ***Grappling with Filtration Soiling,*** Carpet Cleaning Basics, St. Petersburg, Florida