

Modeling Sorption and its Impact on Perceived Indoor Air Quality

Wafa Sakr

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ABSTRACT

Modeling Sorption and its Impact on Perceived Indoor Air Quality

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A variety of studies have demonstrated that building materials, in addition to being an important source of indoor pollution through emission, are also capable of changing the concentrations of indoor pollutants by their interaction either with other pollutants that might exist indoors or/and with each other through adsorption/desorption phenomena. This study aimed to investigate and to quantify the impact of sorption processes on perceived air quality using sensory panels as the measuring device.

The experiments were performed in four similar, adjacent, unfurnished offices. Samples of carpet, painted gypsum board, virgin gypsum board, linoleum and Semia were tested individually and as a combination of two materials. To investigate the interaction between the pollutants emitted from the test building materials and the actual room surfaces, the air polluted by two different building materials was mixed in a separate room without the presence of the building materials. Each experiment lasted between one week (adsorption stage only) to 10 days (adsorption and desorption stages). Untrained panels assessed the air quality at specific time intervals after moving the materials into or out of the rooms, depending on the design of each experiment. The results indicated that sorption affects the perceived air quality significantly. For all performed experiments, the presence of an additional room surface (samples of painted gypsum board) together with samples of carpet or linoleum improved the perceived air quality in that room and in

comparison to the air in the room with carpet alone or painted gypsum board alone. The improvement was consistent despite the different kind of building materials used in the experiments, the different panels that performed the sensory assessments and the different environmental conditions for the different experiments. Moreover, adsorption/desorption coefficients for the room surfaces and the painted gypsum board were calculated assuming a Langmuir type of adsorption and when the pollution source was either carpet or linoleum. As anticipated the linear Langmuir model appeared to be suitable for the painted gypsum board and the room surfaces (flat smooth surfaces). In this work, based on sensory data, it was possible to get reasonable values for sorption parameters for painted gypsum board and the room surfaces presumably because the chemicals emitted from the carpet or linoleum used in the experiments were relatively similar in terms of their sorption parameters. The results demonstrated that sensory assessments could be used to derive sorption parameters for common indoor materials interacting with common indoors pollution sources. The outcome is of direct relevance to perceived air quality since the chemicals measured by human subjects are the same ones that affect their assessment of the acceptability of the indoor air and which are usually presented at concentrations too low to be measured by the traditional chemical methods.

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LIST OF SYMBOLES

A_{room}	Area of the room surfaces (m^2)
A_{PGB}	Area of painted gypsum boards samples (m^2)
A_c	Area under the curve (decipol* h)
C_t	The concentration in the room at time (t) (mg/m^3 or decipol)
C_o	Concentration of pollutants in the supply air (mg/m^3 or decipol)
C_e	Equilibrium concentration of the adsorbate (mg/m^3 or decipol)
C_{PGB}	Perceived air quality in the room with samples of painted gypsum board (decipol)
C_m	Perceived air quality measured in the room
C_{carpet}	Perceived air quality in the room that had samples of carpet (decipol)
G_{carpet}	Sensory emission or sensory pollution load caused by carpet (olf)
G_{PGB}	Sensory pollution load caused by painted gypsum board (olf)
k_a	Adsorption rate constant for the room surfaces(m/h)
k_{a1}	Adsorption rate constant for any sink other than the room surfaces (m/h)
k_d	Desorption rate constant for the room surfaces (h^{-1})
k_{d1}	Desorption rate constant from any sink other than the room surfaces (h^{-1})
k_d'	Desorption constant ($\text{mg}/\text{m}^2.\text{h}$)
K_e	Equilibrium constant (m)
L	Loading factor of the room surfaces = room surfaces area / volume of the room (m^{-1})
L_1	Loading factor of the test specimen = surface area of the test specimen/ volume of the room (m^{-1})
M	Mass adsorbed per unit area of the room surfaces (mg/m^2 or decipol* m^3/m^2)
M_1	Mass adsorbed per unit area of the sink (mg/m^2 or decipol* m^3/m^2)

M_e	Mass adsorbed by the unit area of the room surfaces at equilibrium (mg/m^2 or $\text{decipol} \cdot \text{m}^3/\text{m}^2$)
M_{e1}	Mass adsorbed by the unit area of a sink at equilibrium (mg/m^2 or $\text{decipol} \cdot \text{m}^3/\text{m}^2$)
N	Air exchange rate (h^{-1})
Q	Airflow rate (m^3/h , l/s)
RH	Relative humidity (%)
T	Temperature ($^{\circ}\text{C}$)
t_s	Saturation time (h)
V	Volume (m^3)
θ	proportion of available adsorption sites occupied
$1 - \theta$	Surface sites that are vacant

LIST OF ACRONYMS

ACH : Air Exchange Rate

ASHRAE : American Society of Heating, Refrigerating and Air Conditioning Engineers

CEN : European Committee for Standardization

CLIMPAQ: Chamber for Laboratory Investigations of Materials, Pollution and Air Quality

ECA : European Concerted Action

U.S. EPA: United States Environmental Protection Agency

FLEC : Field and Laboratory Emission Cell

IAQ : Indoor Air Quality

RH : Relative Humidity

VOCs : Volatile Organic Compounds

TVOC: Total Volatile Organic Compound

WHO : World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Indoor air quality problems

The high population, the demand for better housing conditions, the improved life standards and the need to reduce energy expenditure on heating, ventilation and cooling systems are all factors behind the health and comfort problems related to the indoor environment. New building materials and furniture that contain more artificial components are more in use, while at the same time, less outdoor air is allowed to enter as buildings have become better isolated and less ventilated. The combined effect of the reduced outdoor air ventilation rate and the use of new building materials have caused a high concentration of indoor contaminants and more complaints about indoor-air-quality related symptoms, known as Sick Building Syndrome (SBS). The term (SBS) is used to describe the acute health effects and discomfort (headache, eye, nose and throat irritation, dizziness, fatigue, difficulty in concentration, etc) that building occupants experience when they spent some time indoor, but no specific illness can be identified (ECA, 1989, US EPA, 1991).

During the last two decades, it was often believed that Volatile Organic Compounds (VOCs) are indoor pollutants that could cause SBS (WHO 1989, Nielson 1987; Skov et al. 1987; Molhave 1998). VOCs has been defined by the WHO working group as organic compounds with boiling point ranged from 50°C to 260°C (WHO 1987). Building materials, furniture and office equipments were found to be the major VOC sources indoors (Fanger et al. 1988, Wolkoff, 1995). Recent studies suggest that many VOCs

other than those defined by the WHO, and non-volatile organic compounds could cause an increase of SBS. Moreover, experimental evidence has shown that reactive chemistry may produce strong eye and airway irritants (Wolkoff, 2001).

The diversity of the sources and types of indoor contaminants, and the fact that people spent most of their time indoors where they are continuously exposed to indoor pollutants that affect their health, comfort and productivity, make indoor air pollution a topic that attracts the attention of many researchers in different parts of the world.

1.2 Sorption phenomena

Applied in most natural physical, biological and chemical systems, sorption is a generalized term for both adsorption and absorption. Adsorption involves separation of a substance from one phase accompanied by its accumulation at the surface of another and absorption indicates the uptake of substance into the physical structure of the solid. Desorption, on the other hand, refers to reversal of the adsorption and involves the release of what was adsorbed back into the original phase.

Sorption occurs outdoors, indoors and at the interface in between (Weschler, 2002). Most of the existing adsorption research is directed toward industrial applications that involve the use of prepared adsorbents to achieve high rate of adsorption.

According to Slejko (1985) four types of adsorption could be distinguished: exchange, physical, chemical and specific adsorption. Exchange adsorption involves electrostatic attachment of ionic species to sites of opposite charge at the surface of an adsorbent. Physical adsorption is expected to be reversible as the adsorbate in this case is bound to the adsorbent by relatively weak intermolecular Van Der Waals forces. Chemical

adsorption involves a reaction between an adsorbate and an adsorbent, hence forming a stronger bond than that generated from the physical Van Der Waals forces. Specific adsorption involves binding of molecular groups without chemical transformation (e.g. polar adsorbate binding to polarized adsorbent surface).

Adsorption is affected by number of parameters. For adsorbate there are concentration, molecular structure, molecular polarity, and the nature of competitive adsorbates. For adsorbent the most important factor that determine the equilibrium capacity is the surface area, the physicochemical nature of the surface and the availability of that surface to adsorbate molecules or ions. System parameters as temperature and pH could have an impact on adsorption if they effect changes in any of the aforementioned parameters (Slejko, 1985).

Adsorption and desorption are limited by an equilibrium state. The time required to reach equilibrium is an important factor in studying the adsorption processes. Under steady state conditions the rate of adsorption is equal to the rate of desorption and the adsorbed phase equilibrium concentration is related to the free phase equilibrium concentration and to the temperature and gas phase pressure of the considered system (Axley, 1991). When the relationship between the concentrations of the two phases (adsorbed and free) is reported at constant temperature and atmospheric pressure, it is called adsorption isotherm. Experimentally determined adsorption isotherms, may be approximated by one of the following equilibrium models: The linear model, Langmuir model, Brunaur-Emmett-Teller (BET) model or Freundlich model. The first three have theoretical basis while the last one is empirical.

In this document the term sorption refers to (adsorption and absorption).

1.3 Sorption and indoor air quality

During recent years a variety of studies have demonstrated the fact that building materials with a large surface to volume ratio, in addition of being an important emission source for VOCs indoors, they influence the dynamic variation of VOCs concentration in a space by their interaction with VOCs through the sink effect (adsorption/desorption) (Seifert and Schmal 1987; Berglund et al., 1989; Colombo et al., 1993; Jorgensen et al., 1993; Kephelopoulous et al., 1996; Tirkkonen and Saarela 1997; Won et al. 2001). Although the uptake of VOCs will lower their peak concentrations, the subsequent slow re-emission at low concentration will prolong the presence of VOCs in indoor air and make the building materials responsible for indoor air pollution for a long time (Nielsen, 1987; Sparks et al., 1991; Schlitt and Knoppel, 1997). The low emitting building materials and furniture that are recently being used in many countries also play a role in polluting the indoor environment through sorption /re-emission, as a non- emitting material in contact with polluted air will act as a sink as long as the concentration of a compound in the surrounding air is higher than the gas phase equilibrium concentration of this compound within that material, becoming in itself an emitting source when the concentration in the air decreases. An investigator of 'sick buildings' should therefore know that the cause of pollution might well be the re-emission from innocent materials (Berglund et al., 1988). On the other side, many temporary pollution events (painting, cleaning, smoking, etc) are pollution sources from emission caused by sorption of pollutants produced from these activities on many materials found indoors and their subsequent slow desorption,

affecting the indoor air quality well after the pollution event had stopped (Van Loy et al. 2001; Singer et al., 2002a; Salthammer 1999). "For sorbing compounds, more than half of daily potential exposures occurred during non-smoking periods" (Singer et al., 2002b).

1.4 Objective of this study:

Sorption Phenomena have an important impact on the concentration of pollutants indoor, (Seifert and Schmahl, 1987; Berglund et al., 1988; Borazzo et al., 1990; Tichenor et al., 1991; Jorgensen et al., 1993; Colombo et al., 1993; Kephelopoulos et al., 1996) which, in turn, affects the degree of human exposure to indoor air pollution. Therefore, many researchers studied sorption by building materials to better determine its impact on the quality of indoor air. They developed models and data to deal with adsorption of chemical compounds to a variety of indoor surface materials using static or dynamic chamber experiments. Most of this research has been carried out with single VOC and single materials (Tichenor et al. 1991; Kirchner et al. 1995). Only a few of the studies investigated sorption of mixtures of VOCs on single materials or single VOC on combinations of materials (Jorgensen et al. 1993; Wouda et al. 1997). In most of these studies, samples of indoor materials were exposed to an artificially polluted atmosphere (one or several VOCs) with concentration usually much higher than the one found in actual indoor environments. A number of studies were also performed to compare measured concentrations in field experiments with calculated concentrations based on data from small chamber experiments (Zellweger et al. 1995; Dokka et al. 1999; Sparks et al., 1999). The results showed that the predicted concentration (based on chamber

experiments) were considerably higher than the measured concentration in an actual indoor environment.

Despite the improvement achieved during the last few years, in understanding the sorption phenomena and the development of quite a few different sorption models, there is no tool yet to easily and reliably estimate the sorption behavior of different materials and its impact on the indoor environment. The need is still there for a simple sorption model that describes the impact of this phenomenon on the indoor air quality in a real life environment (where different types of VOCs co-exist with different kinds of surface materials under different environmental conditions).

The aim of this study was to investigate the impact of sorption of building materials on perceived indoor air quality, the experiments were performed in real rooms where the pollution sources and the sinks were the actual building materials commonly found in indoors environment.

The ultimate goal of this work is to contribute to the development of a simple and reliable sorption model based on sensory measurements. This approach eliminates the difficulty to simultaneously investigate all the sorption processes as faced by the existing experimental methods. At the same time, it accounts for the ability of the human nose to detect low concentrations of indoor air pollutants. This is needed, as the VOCs concentrations in real life, normally, are several orders of magnitude lower than the ones used to investigate sorption processes and for the diversity of the pollutants that exist indoors.

CHAPTER 2

LITERATURE REVIEW

2.1 Interaction of volatile organic compounds (VOCs) with indoor surfaces and the impact on indoor air quality

Theoretically, the concentration of VOCs indoors depends on the emission rate of these compounds and the ventilation rate. However, a variety of studies have demonstrated that in the real indoor environment, the indoor air pollutants interact with the indoor surfaces by (adsorption/desorption) and this influences the pollutants concentration indoors (Seifert and Schmal 1987; Tichenor et al. 1988; Berglund et al. 1988) and makes it difficult to trace the origin of a specific contaminant in the air of sick buildings by chemical classification (Baird et al. 1987). The first qualitative study of VOCs adsorption on indoor materials was performed by Seifert and Schmal (1987). Their focus was to determine the adsorption and desorption behavior of several organic compounds of different polarity and boiling points with plywood and carpeting. They concluded that no rule could be deduced to predict the sorption behavior of different VOCs with different materials. In The Danish Town Hall Study, 40 parameters describing the indoor climate, or conditions that could influence the indoor climate were measured or registered. A strong inter-correlation was found between indoor environment problem and the fleece and shelf factors. The fleece factor was defined as the area of textile flooring, curtains, and seats divided by the volume of the room, and the shelf factor was defined as the length of all open shelves divided by the volume of the room. Materials capable of depositing/adsorbing pollutants might influence the indoor air quality during the entire

life of the building (Nielson, 1987), the influence can be both negative and positive, but it will become negative with the accumulation of the pollutants. This study provided empirical evidence that re-emission of indoor pollutants, including VOCs from fleecy materials, may contribute to sick building syndrome (Nielson, 1987, Valbjorn and Skov, 1987). In 1988, Berglund et al. presented an extensive literature review on organic compounds indoors with special attention to emission, adsorption and desorption in indoor materials. They also reported that organic compounds adsorbed on building materials in a 7 year old buildings were desorbed when placed in an environmental test chamber and ventilated with clean air over an experimental period of 40 days. They concluded that the exchange of contaminants between room air and room surfaces demonstrates the difficulties to be expected when one wants to trace the origin of a specific contaminant in indoor air. Tichenor et al. (1991) conducted experiments to determine the magnitude and rate of adsorption and desorption of two organic compounds and five materials. The results demonstrated the relevant sink effect parameters for each tested material and the two organic compounds. Kjaer and Nielsen (1991) studied the adsorption and desorption of organic compounds on fleecy materials. They indicated that adsorption/desorption of indoor VOCs on ordinary building materials could have a crucial influence on indoor air quality. Jorgensen et al (1993) performed tests aimed to quantify the adsorption of organic compounds (toluene and α -pinene) on material surfaces (wool carpet, nylon carpet, wooden bookshelf with books, window glass and ceiling sheets of rock-wool). They found that the two organic compounds had significant adsorption and desorption on and from the wool carpet, nylon carpet and wooden bookshelf with books, while window glass and ceiling sheets showed no

adsorption of the two compounds. Meininghaus et al. (1999) studied the sorption and diffusion of VOCs by indoor materials using small-scale chambers. They concluded that the masonry of a room might reduce peak concentration and increase the time required to remove a compound from a space so the right choice of wall materials can have an impact on the indoor air quality. Saarinen and Saarela (2000) investigated the sorption phenomena of VOCs on material surfaces. They exposed five different building materials to VOCs emitted from paint in a model room. They found clear divergences in sorption behavior of different tested materials and that porous materials (gypsum board) are more capable of adsorb and desorb compounds. Jorgensen et al (1993) reported that adsorption/desorption might have an important impact on the ventilation strategy to be applied in office buildings. Tirkkonen and Saarela (1997) studied adsorption of VOCs on interior surfaces in a full-scale building. They compared emission profiles of five different surface materials from a single-family house (tested in small test chambers) with the emission from the corresponding surfaces in the full-scale building (using FLEC-technique). The results demonstrated that the compounds emitted from the floor were adsorbed on other interior surfaces especially on painted walls. Sparks et al. (1999) studied the sink behavior of VOCs from latex paint. Emission models developed using small chamber data were combined with an Indoor Air Quality (IAQ) model to analyze the impact of VOC emissions from latex paint on indoor environments. The experiments were performed in the EPA IAQ test house. The results show the large effects of sinks on the test house concentrations of VOCs from latex paint and that the sink model parameters determined from small chamber tests did not agree with sink model parameters estimated from the test house data. Dokka et al (1999) also compared

measured concentrations in field experiments (a refurbished bedroom) with calculated concentrations based on data from small chamber experiments. Mathematical models were used to predict the concentration of Total Volatile Organic Compounds (TVOC) in the bedroom based on chamber data and compared this with the measured concentration in the bedroom. The results showed that the predicted concentration in the bedroom is up to ten times higher than the measured concentration in the bedroom, but after 29 days the predicted and measured concentration were the same. They mainly referred this discrepancy to the strong adsorption on the bedroom surfaces and the very slow desorption. Moreover, Jorgensen et al. (1999) investigated the interaction between different ventilation strategies and adsorption/desorption of VOCs on material surfaces. They evaluated three different ventilation strategies and each strategy comprised two different ventilation rates (a low rate during the night and a high rate during the day); the only difference between the strategies was the length of day/night periods used. They concluded that ventilation strategy influences the indoor pollution concentrations and that sorption should be included when estimating the concentration variations in a room based on source characteristics and ventilation rates.

2.2 Factors affecting sorption of VOCs on and desorption from building materials surfaces

Sorption is a highly complex phenomenon. It depends on numerous factors, including the material properties, VOC type, and environmental conditions, such as temperature, relative humidity, air velocity, and VOC concentration in the air.

Colombo et al. (1993) studied the adsorption of the following VOCs (tetrachloroethene,

2-butoxyethanol, α -pinene, 1,2,4-trimethylbenzene, 1,4-dichlorobenzene, n-decane, 2-ethylhexanol, n-dodecane) that were different in volatility and polarity, on three widely used building materials (nylon carpet, wall coating vinyl and gypsum board). The experiments were carried out in three small-scale test chambers under controlled temperature, RH and ACH. They found that the adsorption of most compounds on studied materials is remarkable and tends to increase with their boiling point, and that the physico-chemical properties of the adsorbed compounds and the adsorbing materials play an important role. Kephelopoulos et al. (1996) performed a series of experiments aimed to identify how physicochemical properties of chemical compounds (vapor pressure, octanol/water partition coefficient) and experimental parameters (adsorption time and concentration in the chamber air) control the sorption process. They studied sorption of 8 VOCs on glass, different types of carpet, gypsum board and a wall covering in a small scale test chamber. The results showed that the adsorption factor K_{ads} (was defined as the ratio of the mass adsorbed per unit area and the vapor air concentration) strongly depend on VOC vapor pressure and less on their octanol/water partition coefficient and that VOC concentration has no influence on adsorption factor in a limited concentration range, however the adsorption factor decreases at higher concentrations. They also found the longer the adsorption time the smaller appears the desorbed fraction after a given desorption time. Tichenor et al. (1991) studied the sorption of tetrachloroethylene on carpet under different concentrations ($5\text{mg/m}^3 - 50\text{mg/m}^3$) in a small-scale test chamber. They found that the sink strength presented by the equilibrium coefficient (K_e) is independent of the concentration in the test chamber. They also investigated the impact of temperature on sorption of tetrachloroethylene on carpet. Experiments were performed

under two different temperatures (23°C and 35°C). They found that both adsorption and desorption rates were higher at higher temperatures and both the type of material and the type of organic compound affect the rate of adsorption and desorption.

An et al. (1999) studied the adsorption/ desorption of 5 VOCs representative of hydrocarbons, aromatics, ketones, aldehydes and chlorine substituted compounds on carpet, vinyl floor tile, painted drywall and ceiling tile. The tests were performed using a dynamic chamber test system under controlled temperature, RH and ACH. They found that the sink capacity increased linearly with the inverse of VOC vapor pressure and that the adsorption rate constant and the adsorption/desorption equilibrium constant are strongly material dependent. Meininghaus et al. (1999) reported that porous construction materials (gypsum boards) have high sorption capacities for polar VOCs while carpet demonstrates more affinity to non-polar compounds. Won et al. (2000) conducted a series of experiments where eight VOCs were tested with several carpet systems and environmental conditions. The aim was to characterize the sorptive interaction between VOCs and carpet. The experimental system consisted of four small stainless steel chambers. The results showed that the sorption capacities (K_e) were inversely related to vapor pressure and linear relationships were observed between octanol-air partition coefficient and equilibrium partition coefficient (K_e). Variation in RH had significant impact on the degree of sorption for highly water soluble VOC while RH had little effect on sorption parameters for all non-polar VOCs. The concentration of VOC had no significant impact on material-gas equilibrium partition coefficient. To account for the roughness of material surface Kirchner et al. (1996) measured the specific area (defined as the efficient surface area per gram material (m^2/g)) of gypsum board and of acoustic

tiles by using nitrogen adsorption technique. The results showed that the greater the specific area the larger the equilibrium coefficient. Morrison and Nazaroff (2000) introduced R_f "normalized surface area" that is the ratio of the actual surface area of a material (including roughness and porosity) to nominal surface area (or projected surface area).

Van der Wal et al. (1998) investigated the sorption effect of a number of combinations of indoor materials and volatile organic compounds. The aim was to develop a quick screening method to investigate the dynamic sorption effects of indoor materials/compound combinations. They also performed a limited number of experiments to investigate the influence of concentration of pollutants and the temperature on the sorption. They observed an inverse relationship between the extent of adsorption and the compound vapor pressure. They also found that adsorption time, desorption time, concentration of compounds and temperature have an influence on adsorbed and desorbed masses (smaller at higher temperature). Jorgensen et al. (1993) found no measurable effect on the sorption of toluene and α -pinene on the wool and nylon carpet when the relative humidity varied between 20-50%. Jorgensen et al. (1999b) reported the results obtained on adsorption and desorption of two VOCs (toluene and α -pinene) on and from wool carpet, nylon carpet, PVC floor covering, and cotton curtain materials. Air velocity was varied between 0.1 and 20 cm/s (in this work, the air velocity was varied independent of the ACH, which meant that the air velocity would not influence the concentration of pollutant in the test chamber). The results showed that the adsorption of α -pinene was higher than the adsorption of toluene for all tested materials. The air velocity, measured 1 cm above the material surface had no influence on the sorption of

α -pinene and toluene on wool carpet tested with air velocities at 0.1 and 20 cm/s.

Jorgensen and Bjorseth (1999) investigated the impact of material loading factor (the ratio of surface area of the material to the volume of the test chamber) on the sink strength and concluded that the loading factor has no influence on sorption capacity or the mass adsorbed per area at equilibrium. Zhang et al (2002) developed a small-scale test system to conduct sorption tests. The aim of the study was to investigate experimentally the impact of temperature, RH and air velocity on sorption capacity of carpet, ceiling tile and painted drywall. The results indicated that the sorption of VOCs on ceiling tile and painted drywall were relatively weak compared to carpet for the same VOC. Sorption strength of the carpet increased with the increase of temperature from 10.5° C to 23°C while decreased with the further increase of temperature from 23°C to 35°C. The effects of RH and air velocity for all three materials were insignificant for most compounds except dodecane sorption on carpet that increased with the increase of the air velocity. Won et al. (2001) studied sorptive interactions between eight VOCs and various materials. They observed relationships between sorption parameters and chemical vapor pressure and octanol-air partition coefficient, no effect of inlet concentrations on sorption parameters, no apparent effect of ACH and no impact of variation in RH on sorptive interaction between non polar VOCs and building materials but increase in RH increased the degree of sorption of a highly polar compound to carpet. They also found that the extent of sorption is highly dependent on material characteristics. Meininghaus et al. (2000) introduced molecular parameters to characterize the sink effect. They reported that although the sink effect of a compound depends on its boiling point, vapor pressure and octanol /air partition coefficients, these parameters are poor physico-chemical

predictors of sorption. They applied an existing model, Quantitative Structure Activity (QSAR) model, on data from three dynamic sink effect experiments where a mixture of 20 compounds was introduced into small chambers contained samples of gypsum board and wallpaper paste on aluminum plates. They found that compounds with a strong tendency to form hydrogen bonds may exhibit a strong sink effect and the model is reasonably capable to predict sorbed masses of VOCs.

2.3 Overview of the existing sorption models

The aforementioned literatures showed the importance of sorption phenomena on the indoor air quality and the prevalence of sick building syndrome therefore a realistic estimate of human exposure to VOCs indoors requires a knowledge not only on the emission from building materials but also their adsorption /desorption capacity. To better understand this phenomenon, an accurate knowledge about the dynamic behavior and surface sorption of VOCs indoors is essential. Several researchers developed sorption models using different experimental methods and based on different assumptions, the aim was always to find a model that allow the prediction of sorption impact on indoors air quality.

Zhang et al. (2000) classified the existing sorption models into either first order adsorption/desorption rate models or equilibrium-interface models. The model parameters for the first order adsorption/desorption are obtained from experimental data by curve fitting while for the equilibrium interface models the parameters are obtained through independent measurements.

2.2.1 First order adsorption/desorption models:

Assume that the two processes adsorption and desorption occur simultaneously. This model is appropriate for cases of physical adsorption of gases at very low concentration on homogeneous surfaces with many sites available for adsorption (Slejko, 1985). Tichenor et al. (1991) proposed Langmuir model to study the VOC sorption by building materials. The model assumes a monolayer of molecules with all adsorption sites mutually independent and the adsorption on the sink surface is proportional to the concentration in the space. They concluded that Langmuir adsorption theory appears adequate to describe the behavior of smooth materials as wallboard and ceiling tile while desorption kinetics of rough, complex materials, such as carpet appears to be covered by non-Langmuir processes. The drawback of Langmuir model is that it considers only the fast surface sorption process while ignoring the in material diffusion process. To overcome this problem the two sink model was proposed (Colombo et al. 1993, De Bortoli et al. 1996). The two-sink model assumes that the material is composed of both fast sink and slow sink. Dunn and Chen, (1993) proposed the K-diffusion model and the sorption-diffusion hybrid model to account for in material diffusion. Jorgensen et al. (2000) introduced a sink-diffusion model to describe the interaction between material surfaces and VOCs indoors. The experiments were performed in small-scale chambers where toluene and α -pinene were tested with carpet and PVC samples. The results showed that the sink-diffusion model gave a better description of desorption curve than Langmuir model and it improved the predictions for stronger sorption effects.

2.2.2 Equilibrium-interface models:

Assume that the equilibrium condition always exists at the material-air interface and the

sorption rate is governed by the slow diffusion within the material.

The simplest equilibrium-interface model was proposed by (Axley, 1991). He formulated two families of adsorption models: the first is the equilibrium adsorption models based on assuming that zone air concentrations and material concentrations remain in equilibrium at all time. The model uses only one parameter: the material air partition coefficient (K_{ma}). To improve the model the second family (the boundary layer diffusion controlled adsorption models) was proposed. It is based on the use of boundary layer theory to model the rate of mass transfer from the bulk through the boundary layer to the material. To consider the diffusion in the material (Little and Hodgson, 1996) proposed a strategy to characterize homogeneous diffusion-controlled indoor sources and sinks. They used Fick's law to describe the in material diffusion process. The parameters for the diffusion-controlled sink model (K_{ma} , D_m) are physical properties of the material and can be measured independently. Bodalal et al. (2000) developed a novel method to determine the diffusion coefficients and the partition coefficient. Experiments were conducted in two identical small-scale test chambers. The tested materials were: plywood, vinyl floor tile and carpet. Tested materials were placed between the two chambers and VOC compound was introduced to one chamber and gas samples were collected from both chambers to be analyzed by GC/FID. The results showed that VOCs with largest molecular weight had the smallest diffusion coefficient and VOCs with lowest vapor pressure had the largest partition coefficient. Kirchner et al. (1996) used a microbalance to measure material properties. In this method sample of tested material is placed on a microbalance inside a small-scale chamber. The chamber was then flashed by gas containing a known concentration of VOCs. The sorption is measured from the weight increase of test sample

by time. Meininghaus et al. 1998 developed CLIMPAQ method to measure the diffusion and sorption properties for two VOCs (n-octane and ethyl acetate) and 9 building materials (gypsum board, carpet, aerated concrete, solid concrete, brick wall, wallpaper with paste, acrylic paint on woodchip paper, and PVC floor covering). The materials to be tested were placed between two small-scale chamber type CLIMPAQ. Air with constant concentration of VOC was introduced to one chamber and clean air to the other chamber. Concentrations were measured on both sides of the material with photo acoustic detector. All tested materials showed measurable permeability except PVC and both concrete samples had high sorption capacities for ethyl acetate. Kirchner et al. (1999) compared three experimental methods used to test sorption and diffusion properties of a material. The methods were: the microbalance, the cup and the CLIMPAQ method. They concluded that the microbalance and the cup methods are easier to implement than CLIMPAQ method but their drawback is that testing has to be done at unrealistic high VOC concentrations. The advantage of the CLIMPAQ method is the possibility to characterize simultaneously both sorption and diffusion coefficients and can be set up for more realistic VOC concentrations.

In addition, numbers of numerical models have been developed to describe sorption phenomena and to predict the impact of sorption on indoor air quality. Yang et al. (2001) reported a numerical model (CFD model) to study the indoor air quality in a room with different emission sources, sinks and ventilation methods. Murakami et al. (2003) proposed physical models for sorption of VOC that are used for analyzing numerically the transportation of VOCs from building materials in a room. The performance of the proposed physical models was examined numerically in a test room with a technique

supported by (CFD). The results of numerical prediction show that the physical models and their numerical simulations explain the mechanism of the transportation of VOCs in a room.

2.4 Sensory evaluation and sorption

Sensory evaluation is based on the use of human subjects as measuring instruments. The nose is a sensitive instrument; it perceives the presence of pure chemicals and chemical mixtures at levels much lower than the detection limit of most conventional analytical instruments (ECA-IAQ, 1999). In fact, humans perceive the air by two senses: the olfactory which is situated in the nasal cavity and is sensitive to odor, and the general chemical sense that is situated all over the mucous membranes in the nose and the eyes and is sensitive to irritants in the air. The combined response of these two senses determine the perceived quality of the air (fresh, pleasant, stuffy, irritating.....) (CEN report,1998). Olfaction distinguishes itself from the chemical sense in remarkable variation in sensory quality such as fishy, floral and so on (Cometto-Muniz and Cain 1995). The two senses are influenced differently by adaptation (Engen, 1986). The olfactory sense is sensitive to odors and likely to adapt while the common chemical sense is sensitive to irritants and not likely to adapt (Gunnarsen, 1990).

Historically, the presence of odor in indoor environment has been associated with dangerous places having unsanitary conditions. Moreover, odor in indoor environments is undesirable because it may indicate an annoyance factor for the exposed occupants, low air exchange rate between indoor and fresh outdoor air or the emission of VOCs (Moschandreas, 1992). The notion that odor level perceived by visitors to an occupied space could offer a quantitative criterion for ventilation requirements in buildings goes

back to 1936 when Yaglou applied a psychophysical scaling to study the level of occupancy odor depended on ventilation rate in nonsmoking environments. He concluded that the range of ventilation rate should depend on the occupancy density. Both American and European standards have relied explicitly on Yaglou's results. In 1981 the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) published its standards on ventilation for acceptable indoor air quality (ASHRAE Standards 62) that defines acceptable air as the air to which 80% or more of the people exposed to it do not express dissatisfaction. Based on that, two ventilation rates were determined for both smoking and nonsmoking environments. The European committee for standardization in its report, published in 1998, classified the indoor environment in three categories A, B and C where the desired perceived air quality expressed as percentage dissatisfied was 15%, 20% and 30% respectively assuming that the occupants are the only source of pollution. They accord a ventilation rate needed for not to exceed the desired percentage dissatisfied for each category and thus for no smoking environment and for 20% and 40% smokers.

However, the recommended ventilation rate did not prevent serious complaints concerning air quality in many buildings. It was also found that human bioeffluents comprise very little of the pollution sources, whereas materials in spaces and ventilation systems were the major cause of the poor air quality in many buildings (Fanger, 1989). By acknowledging these new sources of pollution, most of the existing ventilation standards were modified.

The introduction of the olf unit (Fanger, 1988) makes the quantification and the comparison of different pollution sources possible. Fanger suggested quantifying the

sensory pollution for a material by the number of equivalent persons (olfs) required to provide the same level of annoyance (percentage dissatisfied) as the tested material. One olf is the emission rate of air pollutants (bioeffluents) from a standard person.

The decipol was introduced to quantify air pollution perceived by humans, one decipol is the pollution caused by one olf ventilated by 10 l/s of unpolluted air. Using olf and decipol, Fanger introduced the new comfort equation for indoor air quality. The equation incorporates all pollution sources in a space to derive the ventilation rate that is required to achieve an acceptable air quality.

$$G=0.1 (C_i-C_o) Q \dots\dots\dots (2.1)$$

Where: G: total pollution load or source strength (olf)

C_i : perceived indoor air quality (decipol)

C_o : perceived outdoor air quality (decipol)

Q: outdoor air ventilation rate (L/s)

Since then many researchers used the comfort equation to investigate the additivity of different pollution sources that exist in one place (Lauridsen et al.1988, Bluyssen and Fanger 1991, Iwashita and Kimura 1995, Wargoscki et al. 1996, Blussen and Cornlissen, 1997). These studies used different sources of pollution, different pollution loads, different kind of panel (trained, untrained), and different experimental procedure. However, none of these studies considered sorption phenomena, the investigated combinations of materials were always placed together in the same space (decipolmeter or chamber). The compounds emitted from one material could be adsorbed on the other material surfaces and result in changing the sensory pollution load of each individual material when it is placed with other materials. The magnitude of this change depends on

many factors like the nature of the tested materials, the environmental conditions of the experiments, the length of time for which the materials were placed together before the sensory assessment. Wargoski (1999) extensively reviewed the previous studies on addition of sensory pollution sources and he pointed to the sorption process as being responsible for the discrepancy between the predicted and the measured pollution load especially when experiments were performed with a mixture of building materials with at least one fleecy material included. He recommended that sorption should be controlled in future studies on addition of sensory pollution sources.

On the other hand, Gunnarsen et al. (1999) used sensory evaluations to investigate the impact of intermittent ventilation strategy on perceived air quality in comparison with continuous ventilation. Experiments were performed both in laboratory (using small scale chambers) and in office buildings. The results indicated improvement in perceived air quality when a continuous ventilation strategy was applied. Haghighat et al. (2000) and Sakr et al. (2000) conducted a series of experiments aimed to study the impact of the operation of ventilation systems and the combinations of several building materials on perceived air quality. They used small-scale chambers to investigate the air quality under intermittent and continuous ventilation conditions and to establish the exposure-response relationships for the tested material. The results showed that intermittent ventilation reduces the daytime air quality and that perceived air quality may improve when two materials are presented at the same space. Results from these two studies indicated that sorption could have an impact on the perceived air quality. For ventilation strategy experiments, the deterioration in perceived air during the day time could be referred to the increase in pollution level caused by the reemission of pollutants that were adsorbed

during the night when the ventilation system was turned off and concentration of pollutants were high. Moreover, the improvement in perceived air quality when two materials were placed in the same place, was probably due to the interaction between the two materials, i.e., the emission from one material being adsorbed by the other, which indicates that sorption may have a positive impact on the perceived air quality.

A limited number of studies used sensory measurement to study directly the phenomenon of sorption. Wouda et al. (1997) conducted chemical and sensory experiments aimed to investigate the sorption effect of a mixture of 12 compounds on the following individual and combined indoor materials: empty chamber, carpet tiles, curtain, gypsum board, and combination of carpet/curtain and carpet/curtain/gypsum board. The experiments performed in 15-m³ chamber for which the inside surfaces were covered by Teflon. For sensory evaluation, air was exhausted via a Teflon tube through one of the walls to a decipol meter*. Air loaded with chemicals (12 compounds) was supplied to the chamber for 48 hrs. After the air supply was stopped the concentration during the desorption period was measured chemically and sensory. Air samples were collected on Tenax tubes and analyzed with gas chromatography. Before the sensory experiments, a panel was selected and trained. Sensory evaluations conducted by a trained panel, were made 1, 24, and 48 hrs after the supply of chemicals had stopped. The surface area under the decay curve (the relationship between perceived air quality in decipol and time) represents the sensory desorption for each tested material and combination of materials.

*Decipol meter: consist of a three liter jar made of glass covered with a plastic cap, a fan and a diffuser. The cap has two holes, the fan is placed in one of them to suck the air through the jar, the fan is selected to produce at least 0.9 L/s. On top of the fan, a cone diffuses the exhausted air. To train the panel, different concentration of 2-propanone are generated by different decipolmeter serve as reference for the panel. During the training, several unknown decipol levels are evaluated several times using the reference. The panel members are also exposed, during the training to pollution sources other than 2 propanone. (Bluyssen and Cornelissen 1995, Bluyssen and et al. 1996)

The sensory and chemical measurements showed that the tested curtain is a weak sorbant in comparison with the tested carpet and gypsum board. The data of the individual materials were added to see if the desorbed mass of combination of materials could be predicted from the data of individual materials.

The results of calculations were compared with the measured data for combination of materials. The results showed that gypsum board had a very strong adsorption for polar VOCs and a relatively small desorption. The results from the chemical experiment indicated that for the more volatile organic compounds the desorbed mass of individual materials could be used to give a possible prediction of the desorbed mass of combination of material. No such correlation was found from the results of the sensory experiment. This could be due to the few points used in the regression analysis (3 points: after 1, 24, 48 hrs), which might have affected the accuracy of the fitted curve. The comparison of chemical measurements with sensory measurements showed that the chemical decrement of the tested compounds proceeds faster than the sensory decrement, which means that a trained sensory panel is able to detect far lower concentrations than the used chemical detection methods.

Kjaer et al. (1996) studied the sorption behavior of building materials while air from a recently renovated office was passed through small test chambers that contained samples of waterborne paint applied on tinned steel plates and carpet. The desorption of VOCs from the test samples was analyzed chemically and sensory. An untrained panel of 22 persons assessed the air quality of the exhaust air from the small chambers (CLIMPAQ), in terms of acceptability and odor intensity. Although the sensory evaluations were not very successful, the authors concluded that it is possible to calculate the impact of the

sinks on the indoor air quality by comparison with indoor relevant thresholds for odor and mucous membrane irritation.

2.5 Conclusion

- Sorption could have a significant impact on the concentration of pollutants in indoor air (Seifert and Schmahl, 1987; Berglund et al. 1988; Borazzo et al. 1991; Jorgensen et al. 1993; Kephelopoulos et al. 1996; Tirkkonen and Saarela 1997; Spark et al. 1999; Jorgensen et al. 1999;Saarinen and Saarela,2000; Won et al. 2000) and that would affect the human exposure to indoor air pollution (Nielson, 1987; Valbjorn and Skov, 1987).
- Sorption is affected by the physical properties of building materials, the chemical properties of VOCs (Colombo et al. 1993; Kephelopoulos et al. 1996; Van der wal et al. 1998; An et al. 1999; Meininghaus et al. 1999; Meininghaus et al. 2000; Won et al. 2000) and the environmental conditions:
 - Temperature (Tichenor et al. 1991; Van der Wal et al.1998; Zhang et al. 2002)
 - Air velocity (Jorgensen et al 1999b, Zhang et al.2002)
 - Relative humidity in the case of polar compound (Won et al. 2000; Won et al. 2001; Zhang et al.2002)
- According to the assumptions used to describe the surface sorption, the existing models could be classified in two categories regardless of the approach used to develop the model (Zhang et al. 2000):
 - The first order models (Tichenor et al. 1991, Colombo et al.1993, Bortoli et al. 1996; Jorgensen et al. 2000)

The equilibrium interface models (Axley et al. 1991; Little and Hodgson,1996)

- Sorption can be detected by conventional experimental methods so it could be detected by sensory measurements as a sensory panel is able to detect far lower concentrations of the mixture than the chemical detection methods (Fanger,1988; Wouda et al. 1997; ECA-IAQ,1999)
- Due to the intensive previous efforts in studying the sorption phenomenon, a big improvement was achieved in understanding the different processes and factors influencing this phenomenon. Several models were developed aimed to investigate how this phenomenon affects the indoor environment, but none of the existing models could easily and reliably be used to estimate the sorption behavior of different materials and its impact on indoor environment.

Table 2.1. Summary of selected literatures on sorption phenomena conducted to date

Literature	Objectives	Methods	Results
Seifert, B and Shmahl, H.J. (1986)	To quantify sorption effects for organic compounds present in indoor environment	Experiments were conducted in small-scale glass chamber. 20 VOCs (different in polarity and boiling point) and lindane were tested with 4 building materials (plywood, 2 kind of carpet, muslin). Concentration levels: 5-35 mg/m ³ . Analyses of concentration were done by GC.	Indoor organic compounds tend to be adsorbed on indoor surfaces (only during the first 2-3 hrs the concentrations in the air depend on ACH, then sorption was dominant). No rule to predict the sorption behavior of different VOC with different materials. SVOCs (lindane) are readily retained on textile surfaces and their desorption is slower than VOCs.
Nielsen, P.A (1987)	To find the factors influencing the SBS. The possibility of potential pollutants-their effect on SBS and their release mechanism	Measurements were performed in 14 town halls in Copenhagen, with a questionnaire study and a clinical study of 4369 employees. 30 different factors or parameters describing the indoor climate have been measured. Fleece factor and shelf factor were included in this study.	A strong inter-correlation was found between indoor air climate problems and fleece factor and shelf factor. It is difficult to ventilate fleecy surfaces since the air circulation is restricted within the materials. Under special conditions the pollutants may be released again and may affect the indoor air quality.
Berglund, B. et al. (1988)	Review the literature, presents the results of a field study and gives recommendations on indoor air pollutants with respect to emission/sorption effects in building materials		A new building needs a gassing-off period for at least 6 months Used materials from 5-10 year old building may still emit low and constant concentration of pollutants Compounds are adsorbed from the room air to indoor materials and then desorbed again when the materials are ventilated. This exchange explains the difficulties to distinguish between a healthy and sick building by chemical classification.

Table 2.1. Continued

Literature	Objectives	Methods	Results
Tichnor et al. (1991)	<p>To determine the magnitude and rate of adsorption and desorption of vapor phase organic compounds for several materials.</p> <p>To modify an IAQ model to incorporate adsorption and desorption.</p>	<p>Five materials were evaluated: carpet, painted wallboard, ceiling tile, window glass and upholstery. Two organic compounds were tested with each material (tetrachloroethylene and ethylbenzene)</p> <p>Sample of sink material was placed in test chamber (23 °C, 45% RH, 1ACH) the test compound was added to the chamber at a constant rate for 48 hrs then the flow with the compound was shut off and replaced by flow from the clean air system. The concentration of the test compound was monitored at the outlet of the chamber by GC. Data were analyzed assuming Langmuir type adsorption to determine k_a, k_d, k_e and M_e</p>	<p>Window glass had no sink effect. Both the type of material and the type of organic compound affect the rate of adsorption /desorption and the equilibrium mass in the sink.</p> <p>Higher temperature increases both adsorption and desorption rate constants.</p> <p>Langmuir adsorption theory is adequate for smooth materials (wallpaper, ceiling tile).</p> <p>Materials with rough surface (carpet) is governed with no Langmuir processes</p>
Axley, J.W. (1991)	<p>To provide a means to identify the circumstances under which sorption phenomena may come to be significant.</p>	<p>Two families of adsorption models (the Equilibrium Adsorption models and the Boundary layer Diffusion Controlled Adsorption models) are formulated based on fundamental principle of adsorption that may be used for whole building contaminant dispersal analysis. The linear variants of each family are applied to model the adsorption dynamics of formaldehyde in gypsum wall and compared to measured data.</p>	<p>Consideration of the dynamic character of adsorption provided by these models indicates that simple physical adsorption and desorption transport processes affect significantly the dispersal of contaminants in buildings.</p>

Table 2.1. Continued

Literature	Objectives	Methods	Results
Jørgensen et al.(1993)	To quantify adsorption and desorption using a simple test chamber method and to predict diurnal concentration variation of VOCs in indoors air.	Experiments were performed using a glass test chamber (1.03m ³) Test materials: window glass, nylon carpet, wool carpet, ceiling sheets of rock-wool, wooden bookshelf with books and papers each material was tested with two compounds: toluene and a-pinene. Sample of sink material was placed in the chamber. The compound was added to the chamber inlet and the concentration was measured at the exhaust using photo acoustic spectroscopy. Test conditions: T= 22°C, RH=20-50%, ACH=1h ⁻¹ Obtained data were analyzed assuming Langmuir adsorption isotherm that yielded values for M _{eq} , k _a , k _d , and K _e	The results showed significant adsorption on and desorption from both types of carpets, wooden bookshelf with book and papers while window glass and ceiling sheets of rock wool showed no adsorption of the two compounds. A model based on Langmuir isotherm appears adequate to describe sorption phenomenon. The rate constants in the model can be applied to predict the impact of sorption on indoor air quality. The results were used to predict diurnal concentration variations in an indoor environment during different ventilation strategies.
Colombo et al. (1993)	To quantify the sorption phenomenon for selected VOCs and surface materials in order to estimate the importance of this phenomenon for human exposure.	Experiments were carried out in three small test chambers (two had glass wall and one had electro polished stainless steel). T= 23° C, RH= 10-70%, ACH=0.1 h ⁻¹ , LF= 1.1 and 1.8 m ² /m ³ . Compounds used for adsorption had different volatility and polarity. Tested materials: carpet, gypsum boards and vinyl wall coating, were exposed to constantly emitted vapors of selected compounds into small test chambers and measuring their concentration as a function of time until the steady state. The concentration time data were the input for an existing model with five-rate constants two of them being known the others characterizing a two-sink adsorption phenomenon (one reversible and the other irreversible). For validation some experiments were carried out under static conditions.	The results show that adsorption occur to at least two different sinks with different rate constants in the same material. The adsorption of most compounds tends to increase with their boiling point but it also depends on other physico-chemical properties as well as the adsorbing materials.

Literature	Objectives	Methods	Results
Kephaliopoulos et al. (1996)	To identify how physicochemical properties of chemical compounds (Vapor pressure, o/w partition coefficient) and experimental parameters (adsorption time and air concentration) control the sorption process	Sorption tests were carried out on: glass, gypsum board and four different types of carpet. Three different test chambers were used. Temperature RH and airflow rate were controlled in all chambers. Two types of experiments were done: <u>dynamic sorption</u> with air flow through the chamber and <u>simultaneous introduction</u> of vapor at constant rate and <u>static sorption</u> by injection of vapors into the chamber and follow up of the concentration decay. Vapor concentrations in the chamber were determined by GC. Two sinks model has been used throughout the work to derive adsorbed masses. Before each experiment the carpet has been heated overnight (70°C) under a flow of clean air to remove any previous adsorbed vapor.	The K_{ads} is constant in a limited concentration range and decreases at higher concentrations. Large errors are possible if the adsorption on chamber walls is not taken into account. The longer the adsorption time the lower the desorbed fraction after a given desorbed time.
Sparks et al. (1996)	To develop a generalized mass-transfer model for gas phase to predict VOCs emissions rates from indoor pollutant sources	The research program included chamber and test house experiments using p-dichlorobenzene (the active ingredient in many moth cakes) sources and a synthetic stain source. The experiments were designed to ensure that the full range of air velocities in indoors was covered. A series of experiments were conducted to determine the mass transfer coefficient from the source in both small chamber and IAQ test house. The source concentration was constant and the equilibrium concentration was the vapor pressure at the temperature of the experiments. Two types of test were conducted: static chamber test to determine the vapor pressure of p-dichlorobenzene. And 4 dynamic tests with different target air velocities and the weight loss of source was measured. Experiments were also conducted in an IAQ test house to extend the data developed in small chambers.	The mass transfer model provides a better fit to data from indoor air quality test house than does the empirical first order decay model. The mass transfer model can be used in IAQ model to predict building pollutant concentrations. The advantage of the mass transfer model is that data from one situation can be easily applied to other situations if the air velocity and the source area are known. A correlation of Nusselt and Reynolds numbers using data from controlled experiments conducted in dynamic chambers and in IAQ test house allows estimating mass transfer coefficient and scaling data from the chambers

Table 2.1. Continued

Literature	Objectives	Methods	Results
Kjaer et al. (1996)	To provide a basis to design a general test method for building material labeling with respect to their sink effect.	Six Climpaqs were used: two empty, two contained samples of paint on steel plates, and two contained carpet. ACH=1.3 h ⁻¹ and velocity=0.1m/s. After 5 days chemical and sensory measurements were done. On day 6 three Climpaqs were moved to an office that had been renovated six month earlier and stayed for 20 days, then chambers were moved to the laboratory and flushed with clean air for chemical and sensory tests.	The results of chemical analysis in the desorption phase showed a correlation between the desorbed amount (expressed as percentage of concentration in the office air) and the GC retention times of the VOCs that is related to VOCs vapor pressure The results of sensory tests did not agree with the results of chemical test
Tirkkonen et al.(1997)	To investigate the adsorption of VOCs on interior surfaces in full scale building	The emission profiles of five different materials from an ecologically designed house were tested in laboratory in small test chambers (0.1-1 m ³ stainless steel test chambers) were compared with the emissions of the corresponding surfaces in a full scale building determined using FLEC technique. Laboratory test conditions: T=23°C, RH=45+5%, ACH=0.5 h ⁻¹ L.F* =0.41m ² /m ³ Emissions were measured after 3 days, 2weeks, 14weeks and 26 weeks. In the building, measurements were performed four months and 7 months after finishing the building work inside. Tenax tubes were used for sampling.	The floor construction in the ecological house was the main source of VOCs in the building. During the first month the ventilation was low and the emission from the floor construction was high that resulted in high concentration of VOCs indoors and adsorption of VOCs on other surfaces in the building. The most significant adsorption was on the painted wall constructions. The decay of the adsorbed compound was low.

*Loading Factor: is the ratio of the surface area of the material to the volume of the test chamber

Table 2.1. Continued

Literature	Objectives	Methods	Results
Wouda et al. (1997)	To evaluate (chemically and sensory) the sorption effects of chemicals on combined materials in comparison to sorption effects on the individual materials.	The experimental set up comprised a chamber of 15 m ³ (covered at the inside with Teflon) the air was exhausted via a Teflon tube to a decipol meter for sensory evaluation. Chemical measurements were done directly in exhaust air Building materials: carpet tiles, curtain textile, gypsum board, (carpet + curtain), and (carpet+curtain + gypsum board) as combinations. Air flow rate = 30 m ³ /h, ACH=2h ⁻¹ , T=23°C, RH=45%. ASVR*=2.4m ³ /m ² .h for carpet, 1.8 for curtain and 2.1 for gypsum board. Air velocity at the surface=0.1 m/s. The experiments were performed with mixture of 12 compounds added to the supply air for 48 hrs then the supply of mixture was replaced by clean air and during the desorption period the concentration was assessed chemically (Tenax tubes) and sensory (trained panel) sensory evaluations were performed 1, 24, and 48 hrs after the supply of chemicals was stopped.	Sensory and chemical tests show that curtain is a weak sorbent in comparison with carpet and gypsum board. The results from the chemical experiments give the indication that for the more volatile compounds the desorbed mass of individual materials are additional. Making prediction of the desorbed mass of combinations possible. The results of the sensory experiments showed no such correlation. The chemical decrement of the tested compounds proceeds faster than the sensory decrement.
Van Der Wal et al. (1998)	To develop a quick method to investigate the dynamic sorption effects of indoor material/ compounds combinations. The results could be used for ranking the materials.	The experiments were conducted in a small-scale chamber (1 m ³) taking air from a large room (15 m ³) where the air with vapor of single compound or of mixture of compounds was mixed with the main supply air. The chamber was ventilated with conditioned air: T=23°C, RH=45% and ACH=1 h ⁻¹ , L.F=1m ² /m ³ . The conditioned air was loaded with VOCs during adsorption time 6hrs then it was replaced with clean air (desorption) for another 6 hrs. The sink materials (different types of carpet, curtain, vinyl wallpaper, particle board, and gypsum board) were placed inside the small test chamber. The concentration in the chamber was monitored (using monitors with data logger). During all experiments air samples were taken by charcoal tubes in the exhaust of the chamber the samples were analyzed by GC. Curves were fitted through the data points with non-linear regression analysis	The data of the experiments with single compound can be used to rank indoor materials in relation to their sink properties. The results indicate an inverse relationship between the extent of adsorption and adsorbate vapor pressure. The adsorption time, desorption time, concentration of compounds and temperature have an influence on adsorbed and desorbed masses.

* Area Specific Ventilation Rate is the ventilation on the unit area of material (= air change rate/loading factor)

Table 2.1. Continued

Literature	Objectives	Methods	Results
Doka et al.(1999)	To compare calculated concentrations based on data from small test chamber experiments with measured concentrations in a controlled field experiment (refurbished bedroom)	<p>The experiments were performed both in small chambers and in the field.</p> <p><u>Chamber experiments:</u> sample of paint on aluminum plate was placed in a small-scale steel chamber (1 m^3). $T=21^\circ \text{C}$, $\text{RH}=53\%$, $\text{ACH}=1 \text{ h}^{-1}$. Samples were collected by Tenax tubes and analyzed by GC. During the first week several samples per day then after one week it was one sample per day. The experiment last for 30 days. The field experiments were carried out in an unoccupied bedroom (20 m^3). The walls of the room were painted with the same paint used in the small chamber experiment. $\text{ACH}=0.15 \text{ h}^{-1}$ the same chemical analysis as in the test chamber were used. The walls consisted of hard particleboard with wall covering, the ceiling was painted particleboard and the floor was covered by carpet. Mathematical models were used to compare the resulting concentration from the two experiments. Since concentration in the small chamber depend on emission (exponential decay) and on loading and ACH. The model was based on mass balance. For the bedroom the sink effect should be included in the model (Tichenor model was modified with an exponential decaying source).</p>	<p>The predicted concentration in the bedroom is ten times higher than the measured concentration, one reason could be the strong surface adsorption and very low desorption another one could be the higher air velocity in the test chamber that lead to higher emission in the chamber compared with the bedroom.</p>
Kirchner et al (1999)	To develop a simple procedure to test the sorption properties and diffusion properties of indoor materials	<p>Three experimental methods were tested in order to evaluate their ability to study sorption and diffusion properties of the materials (Micro-balance method, cup method, and climpac method).</p> <p>Tested materials: PVC floor covering, wallpaper with paste, carpet with SBR backing, acrylic paint on woodchip paper, aerated concrete, solid concrete, brick wall and acoustic tile. These materials were tested with n-octane and ethyl acetate.</p>	<p>Climpac method allows to characterize simultaneously sorption and diffusion coefficients and can be set up for realistic VOC concentration in comparison with the other two methods that they are easier to implement but has to be done with unrealistic high VOC concentrations. The results from the three methods showed a good agreement for the determination of diffusion coefficient.</p>

Table 2.1. Continued

Literature	Objectives	Methods	Results
Jørgensen et al.(1999a)	To investigate the interaction between different ventilation strategies and adsorption / desorption of VOCs on material surfaces.	Sample of nylon carpet was placed in small chamber and exposed to a mixture of toluene and α -pinene at two different source levels (high during the working hours and low during the rest). Three different ventilation strategies were evaluated and each ventilation strategy comprised two different ventilation rates. The difference in the strategy was the length of the day/night period used. The concentration of the test compounds in the test chamber exhaust air was measured using photo-acoustic spectroscopy. One sorption experiment was performed to find the sorption constants at the actual pollution level (analyzed assuming Langmuir type of sorption). EnviSim software was used to model the concentrations in a model room based on the experimental conditions.	Desorption of pollutants adsorbed during the night contribute to a higher concentration during the day when compared with the concentration levels assuming that the sink effect is negligible. The results also show that the influence of sorption has to be included when estimating the concentration in a room based on source characteristics and ventilation rates. By optimizing the ventilation strategy, the desorption of the pollution from the materials could be forced to take place at certain time.
Jørgensen et al.(1999b)	To determine adsorption and desorption of VOCs (in realistic concentration) on materials surfaces and to study the effect of air velocity on adsorption/desorption.	Experiments were performed in four similar small-chambers (50 L) each. Four materials (nylon carpet, wool carpet, PVC floor covering and cotton curtain were tested separately with two organic compounds (α -pinene and toluene). T= 17-35 °C, RH=10-70%, air velocity=0.01-0.22m/s. Each sample of the test material was placed in the chamber and ventilated with clean humidified air at ACH=1 h ⁻¹ . And thus for 14 days after that the clean air was replaced by air with the two compounds for 102 hrs (adsorption period) then the air was replaced by clean air for 102 hrs (desorption period). The concentration of the test compound was monitored at the chamber outlet (Tenax tubes, GC). The one sink model was used to describe experimental results. The second part of the experiment focused on the influence of air velocity on sorption (0.10 and 20cm/sec) the air velocity was varied independent of ACH.	The adsorption of α -pinene was higher than the adsorption of toluene for all the tested materials The ranking of the materials was the same for both chemicals: wool carpet>nylon carpet>PVC coverings>cotton curtain. The air velocity above the material did not influence the sorption of the two compounds.

Table 2.1. Continued

Literature	Objectives	Methods	Results
Jørgensen RB and Bjørseth O. (1999)	To investigate the adsorption and desorption behavior of combinations of materials and compounds in comparison to sorption of single compounds on single materials	<p>Experiments conducted in four small scale test chambers</p> <p>Test materials: two types of carpet (wool and nylon) and the test compounds were: toluene and α-pinene. Controlled parameters: $T=23^{\circ}\text{C}$, $\text{RH}=50.4\%$, $\text{ACH}=1\text{ h}^{-1}$, air velocity over the material $=0.1\text{ m/s}$, and loading: 2.23 and 4.46 m^2/m^3. Before the experiments: carpet was baked-out with 60°C until the emission of test compound was below the detection limits and each test material sample was conditioned for 14 d. At the start of experiment the clean air inlet was replaced by air from a dosing unit with test compounds. Samples of the outlet air were taken each 15,45 and 75 min and then at 2,3,4,5,6,7,8,9, and 12h.</p> <p>Desorption phase started immediately after the adsorption period was terminated. The air from dosing units was replaced with clean air. Samples were collected on Tenax tubes and analyzed by GC. To investigate whether the sorption is additive experiments were conducted with nylon carpet, wool carpet and a combination of both. The one sink model was used and Langmuir adsorption process was assumed.</p>	<p>The results show that the loading factor has no influence on the sorption capacity or the mass adsorbed per area at equilibrium.</p> <p>The presence of two chemical compounds together gives higher sorption than the case of one compound.</p> <p>The higher the K_e the greater the mass adsorbed on the sink at a given concentration.</p> <p>The desorbed masses of individual compounds are additive, making the prediction of the desorbed mass of combinations of compounds possible.</p> <p>The combination of two materials at the same time lead to higher sorption than one material.</p>
Meininghaus et al.(1999a)	To describe an experimental set up aimed at measuring separately transport of VOCs through indoor materials and sorption of VOCs by indoor materials.	<p>Tested materials: six wall coverings, a carpet, chipboard, a PVC floor covering, and a gypsum board. Were consecutively exposed to mixture of 20 compounds with constant concentrations. The material was placed as a membrane between two air compartments (two FLECs were installed face to face). The airflow with mixture of VOCs leading to the primary cell the clean air to the secondary cell. Concentrations in both compartments were measured by collecting samples with Tenax tubes.</p>	<p>Diffusion of VOCs in indoor materials occurs. Base materials that are not in contact with indoor air but which are covered by permeable materials may play a role as sinks. The proposed method Allows for screening of indoor materials with regard to their retention capacities and affinities to organic compounds. With regard to retention capacities the tested materials ranks: Carpet>gypsum board>chipboard>PVC >wall coverings.</p>

Table 2.1. Continued

Literature	Objectives	Methods	Results
Sparks et al (1999a)	To develop a small chamber method to evaluate VOCs emissions from latex paint, to develop a source emission models to predict VOCs emission rates from paint and to determine the sink behavior of VOCs from latex paint	A white interior flat latex wall paint was selected for study. A flow through dynamic chamber testing was used to study emissions from the latex paint; velocity near the test surface 5-10 cm/s. Stainless steel and gypsum board were evaluated as substrates for the latex paint evaluation. Tests were conducted to determine the effect of painting over previously painted surfaces (two previously painted gypsum boards). Samples of tested materials were placed inside the chamber and ventilated with clean air (ACH=0.5). Samples of the chamber outlet air were collected (Tenax tubes) then analyzed (GC). Sampling continued long enough to provide sufficient concentration time data to develop emission models.	The substrate has a major effect on the time history of the emissions. (For stainless steel substrate all the VOCs were emitted in few days while for gypsum board VOCs were emitted for a long time). A mass transfer model provides an excellent description of short and long term latex paint emissions. Only 8 days of small chamber data were required to estimate the parameters for the mass-transfer based models. The latex paint VOCs indoor surfaces combination appears to be a strong sink. The desorption sink constant for latex paint from the chamber data is expected to be much larger than in the test house
Sparks et al (1999b)	To use the model developed from the small chamber to analyze the impact of latex paint on IAQ. To verify the model analysis with experiments in IAQ test house to determine the impact of latex paint on IAQ in a typical residence.	Test house is a typical three-bedroom ranch style with crawl space. The house has a natural gas central force-air heating system and an electrical air conditioning system. The validity of the source model was determined by incorporating the source model into an IAQ model (RISK) that is a multi-room, mass balance model. Two test house experiments were conducted the first experiment to provide insight into the impact on using latex paint on test house. This experiment was designed to check sampling and analysis strategies and to provide data on indoor sinks. The second experiment was to validate the source and sink models and to determine the impact of using latex paint.	The mass transfer model can be combined with an IAQ model to predict the impact of VOC emission from latex paint on indoor environment. The effects of sinks on the test house concentrations of VOCs from latex paint are very large. The sink model parameters determined from small chamber test do not agree with sink model parameters estimated from the test house

Table 2.1. Continued

Literature	Objectives	Methods	Results
An et al. (1999)	To evaluate conditions under which the linear sink model is sufficient and those where more complicated models are necessary and to measure (K_e) for typical interior building materials with compounds represent a broad range of indoor VOCs	<p>Dynamic chamber test system was used to measure adsorption/desorption characteristics for four building materials (carpet, vinyl, painted drywall, and ceiling tile). The five tested VOCs were selected to represent hydrocarbons, aromatics, ketones, aldehydes and chlorine substituted compounds.</p> <p>$T = 23^\circ\text{C}$, $\text{RH} = 50\%$ and $\text{ACH} = 0.5 \text{ h}^{-1}$</p> <p>Chamber air samples were analyzed by GC/FID</p> <p>To analyze the data and to determine K_e for each VOC/material combination, the first order reversible sorption model based on Langmuir isotherm was used.</p>	<p>The linear sink model was appropriate for describing the sink effect for the range of VOC concentration found indoors.</p> <p>Adsorption rate constant (k_a) and adsorption/desorption equilibrium constant (K_e) are strongly material dependent</p> <p>K_e increased linearly with the inverse of VOC vapor pressure</p>
Meininghaus et al (1999 b)	To develop a method to determine diffusion coefficient and sorption capacities of VOCs in indoor materials	<p>Sample of tested materials (gypsum board, carpet, aerated concrete, solid concrete, brick wall, wallpaper with paste, paint on woodchip paper and PVC floor covering) was placed between two Climpaq. They were equally ventilated one with clean air and the other with a constant concentration of added VOC (n-octane, ethylacetate) Concentrations were measured in the exhaust of both chambers from these measurements steady state diffusion coefficients and sorption capacities were calculated.</p>	<p>At low ventilation rates $< 0.5 \text{ h}^{-1}$ diffusion through materials may reduce the concentration of VOCs in a room.</p> <p>The masonry of a room may reduce the peak concentrations and increase the time required to remove compound from the system.</p>

Table 2.1. Continued

Literature	Objectives	Methods	Results
Won et al.(2000)	To characterize the sorptive interaction between VOCs and carpet systems	Four small chambers were used in these experiments. During each experiment one of the chambers was used as a blank and the other three contained carpet. A mixture of 8 VOCs was delivered to the test chambers. Exhaust from each chamber was connected to three-way valve for sequential sampling from each chamber. Each experiment lasted 18 hrs and included an adsorption stage (with chemical injection) and a desorption stage (no chemical injection). Three carpets and two carpet pads were tested. Carpet1/pad1 was tested with three different relative humidity (50, 70 and 80%)within 6 hours of adsorption stage and three inlet gas concentrations.	A linear adsorption/desorption model observed to be appropriate for short –term sorption. Padding appears to be responsible of adsorptive interaction between VOCs and carpet systems. K_e observed to be correlated to chemical vapor pressure and octanol-air partition coefficient. Variations in RH had a significant effect on the degree of sorption for a highly soluble VOCs and a little effect on other VOCs (non polar VOCs). Inlet gas concentration did not have a significant effect on the degree of sorption.
Saarinen et al (2000)	To get more data on behavior of materials where they are exposed to compounds emitted from paint.	Experiments were performed in full scale chamber (model room) Five different building materials (gypsum board, wood fiber board coated with wall paper, chip board coated with plastic sheet, varnished parquet and PVC floor covering) were exposed to paint. Three experiments were performed where two different kinds of interior latex paint were used. The painted surface was glass or gypsum board VOCs concentrations were measured both from the material surfaces (using FLEC) and from the indoor air during the test (samples collected into Tenax the analyzed by GC).	Among the tested materials the gypsum board had the biggest ability to adsorb and desorbs compounds. Clear discrepancies in sorption behavior of the materials were noticed. It is likely that adsorption and desorption were not controlled only by surface phenomena but involved mechanisms such as diffusion.

Table 2.1. Continued

Literature	Objectives	Methods	Results
Zhang et al.(2000)	Review on different VOCs sorption models	Some typical statistical and theoretical models were compared in terms of governing equations, assumptions, model parameter determination and applicability to predict IAQ	The statistical models have some problems such as estimation of model parameters and the difficulty in considering the in-material diffusion process in contrast the theoretical models are more reliable because of the solid physical basis of the model parameters. The theoretical models should be used for IAQ study if the material properties can be accurately measured.
Jorgensen et al. (2000)	To introduce a new and improved model based on surface adsorption/desorption and internal diffusion in the material.	Experiments were performed in small scale glass chambers under controlled parameters: $T = 23.1^{\circ}\text{C}$, $\text{RH} = 51\%$, $\text{ACH} = 1.02\text{ h}^{-1}$ and air velocity $= 0.1\text{ m/s}$. Toluene and α -pinene were tested with nylon carpet, and PVC floor covering. Test materials were conditioned for 14 days before the experiments. Adsorption period=1 week then started the desorption experiment that last for 104 hrs. Samples were collected using Tenax tubes and analyzed by GC. Sorption parameters were estimated using Langmuir model (to find k_a and k_d) and the sink diffusion model together with k_a and k_d previously found. The k_{diff} was found (by iteration until the minimum sum of squared residual was found (residual is the difference between the predicted and measured concentration). SPSS and MathCAD software's were used to solve the mathematical equations.	A new model that count for adsorption/desorption on material surfaces and diffusion into the material was introduced The results showed stronger sorption effect for carpet than for PVC and α -pinene stronger than toluene. In the case of carpet the sink –diffusion model gives better description of sorption than Langmuir model.

Table 2.1. Continued

Literature	Objectives	Methods	Results
Won et al (2001)	To expand the existing data bases associated with the sorptive interaction of VOCs and indoor materials	<p>Four small test chambers (50L) were used in these experiments. One of the four was always used as blank. Mixture of VOCs (8 compounds) was delivered to the four chambers. Samples of sorptive materials (three carpet, three types of gypsum board, vinyl, wood flooring, ceiling tile, fiberglass shower stall, upholstery and unwashed apple) were placed inside the chambers. Dynamic responses in VOCs concentrations were used to determine linear sorption rate coefficients. Samples of the exhaust air from the 4 chambers were directed to an online gas chromatography system. Each experiment lasted 18h (10h adsorption with chemical injection and 8 h desorption). Experimental conditions: inlet gas concentration 6-15 mg/m³, final RH=0%, t=24-25 °C, ACH=0.5h⁻¹)</p> <p>Three different classes of inlet concentrations were studied for each VOC in the presence of carpet1 (2.5, 5 and 15 ppm). Three different ACH were also used with carpet1 (0.5, 2.1 and 3.2/h). Three RH (0%, 50% and 80%) were tested for six different materials.</p>	<p>The results show that the extent of sorption depend on material characteristics. Carpet was the most significant sorptive sink for non-polar VOCs; virgin gypsum board was significant sink for highly polar VOCs. For a given material, the level of sorption is sensitive to chemical properties.</p> <p>RH had no effect on sorptive interactions between non-polar VOCs and indoor materials. However increased RH increase the degree of sorption of isopropanol (a highly polar compound) to carpet.</p> <p>Inlet concentrations had no observable effect on sorption.</p>
Bodalal et al (2000)	To develop a novel method to determine more accurately the diffusion coefficients and the partition coefficients for dry building materials	<p>Tested materials: plywood, vinyl floor tile, and carpet. Before the experiments the materials were cut and placed in an environmentally controlled room (T=23 °C, RH=50%) and ventilated with clean air for 8 weeks. Two identical chambers (50L) were used in these experiments. Test material was placed between the two chambers. VOC compound was introduced to one chamber and gas samples were collected from both chambers to be analyzed by GC/FID.</p>	<p>For the three tested materials the VOCs with the largest molecular weight had the smallest diffusion coefficient and the VOCs with lowest vapor pressure had the largest partition coefficient.</p>

Table 2.1. Continued

Literature	Objectives	Methods	Results
Yang et al. (2001)	To develop a CFD-based model for general IAQ studies. The model integrates the effects of airflow and the mass transfer processes associated with VOC emission sources and sinks to yield detailed distributions of airflow, temperature and contaminants in a building.	An IAQ model that combine several models including room air model, emission source and sink models was used to study indoor air quality in a room with different emission sources, sinks and ventilation methods. Based on the model a computer program (ACCESS-IAQ) has been developed to study the VOC emissions from different types of building materials and to study the VOC sorption by building materials. The program was used to simulate VOC in full-scale room with sources and sinks from building materials.	The numerical simulations showed that when a wet emission source is distributed uniformly across the floor area with sinks from the four walls, displacement ventilation lower exposure of the occupant in the room. Gypsum walls adsorb significant amounts of VOCs during the first hour and act as secondary sources afterwards. The sinks can lower the peak concentration and elevate it after the peak time.
Zhang et al. (2002)	To study the effects of different environmental conditions on VOC sorption by building materials	Experiments were performed using small –scale chamber method. Each test contained an adsorption period where the air with selected VOCs was supplied to the chamber, in which a material sample was placed, and a desorption period where the VOC injection is replaced by clean air supply. Air samples were taken at the chamber exhaust using adsorbent tubes to be analyzed by thermal desorption GC/FID. The VOC sorption by the tested material was found by comparing the measured VOC concentrations with the theoretical values under no-sink condition. Three different types of materials: painted drywall, ceiling tile and carpet and 6 VOCs (represent different kinds of VOCs) were tested under different environmental conditions (temperature, RH, air velocity)	For painted drywall: the effects of environmental conditions on sorption were insignificant. For ceiling tile: the environmental conditions had some effects on sorption (with an increase of temperature, the sink strength of most VOCs decreased. The effects of air velocity were insignificant for almost all tested VOCs) For carpet: the sink strength increased with an increase of temperature from 10.5 °C to 23 °C, while it decreased with an increase of temperature from 23 °C to 35 °C for most VOCs. The higher RH showed no major effect on most VOCs. Higher velocity decreases the sink strength of some VOCs and increases it for others.

CHAPTER 3

INTERACTION BETWEEN BUILDING MATERIALS AND THE IMPACT ON PERCEIVED INDOOR AIR QUALITY

The conducted literature review cited in the previous chapter has demonstrated the fact that building materials, in addition to being a main source of indoor pollution through emission, are also capable of changing the concentrations of indoor pollutants by their interaction either with other pollutants that might exist indoors or/and with each other through adsorption/desorption.

The performed experiments, as detailed below, aimed to investigate the impact of sorption processes on perceived air quality using sensory panels as the measuring device.

3.1 Methods

3.1.1 Experimental Plan

An untrained panel assessed the air quality in four similar offices where the air was polluted either by individual building materials or a combination of two materials. The pollution source varied from one office to another. For experiments 1, 2 and 7, two offices had one material each, another had a combination of two materials and the last office received a mixture of the exhaust air from the two offices with a single material each (see Fig 3.1). Sensory evaluations were performed at specific time after moving the materials into or out of the rooms depending on the design of each experiment (see Table 3.1. for the design and conditions of the performed experiments). Experiments 3 and 4 were performed using the same sensory panel and the same environmental conditions but

with different materials. The same applied to experiments 5 and 6 that had the same sensory panel and environmental conditions (but different from experiments 3 and 4). Experiments 1, 2, 3 and 7 were performed with the same materials but with a different panel and different environmental conditions.

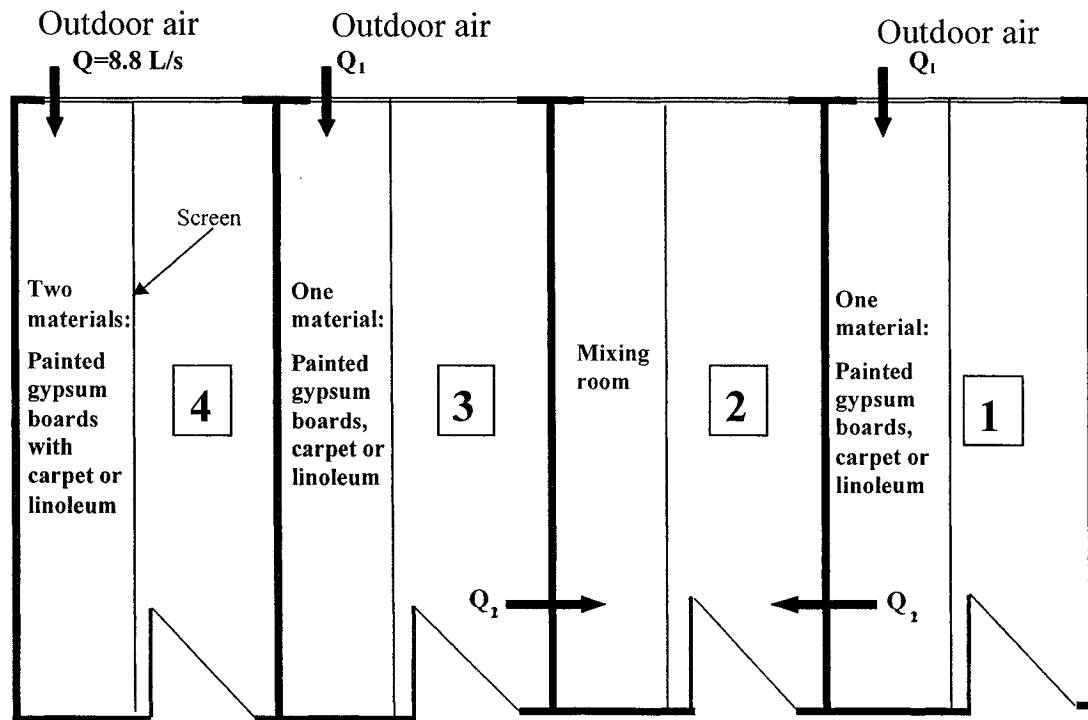


Figure 3.1. Experimental set-up

3.1.2 Facilities

Experiments were conducted in similar, adjacent, unfurnished offices located at the International Centre for Indoor Environment at Technical University of Denmark. Each office had a volume of 40 m^3 and 13-m^2 -floor area made of low polluting polyolefin. The offices had painted brick walls and ceiling tiles made of compressed mineral wool. Each office had one glass window on the external wall.

Table 3.1. Summary of performed experiments design

	Test materials	Sensory assessments	Experiment conditions
<u>Experiment 1</u>	<p><u>Room 1</u>: painted gypsum board (23 m²)</p> <p><u>Room 2</u>: exhaust air from rooms 1&3</p> <p><u>Room 3</u>: carpet (16 m²)</p> <p><u>Rooms 4</u>: carpet and painted gypsum board (16 m²+23m²)</p>	Assessments performed for the empty rooms then 4, 24 and 120 hrs after the materials were placed inside the rooms	<p>Ventilation rate:</p> <p>Room 1: Q₁= 8.8l/s (outdoor air)</p> <p>Room 2: Q=8.8 l/s =2 Q₂ (Q₂=4.4 l/s from rooms 1&3)</p> <p>Room 3: Q₁= 8.8l/s (outdoor air)</p> <p>Room 4: Q= 8.8l/s (outdoor air)</p> <p>Average T= 23.8±0.8° C</p> <p>Average RH = 38 ± 3%</p>
<u>Experiment 2</u>	<p><u>Room 1</u>: painted gypsum board (23 m²)</p> <p><u>Room 2</u>: exhaust air from rooms 1&3</p> <p><u>Rooms 3</u>: carpet (14 m²)</p> <p><u>Rooms 4</u>: carpet and painted gypsum board (14 m²+23m²)</p>	Assessments performed for the empty rooms then 4, 8, 24, 48, 72, 144 and 168 hrs after the materials were placed inside the rooms	<p>Ventilation rate:</p> <p>Room 1:Q₁= 4.4l/s (outdoor air)</p> <p>Room 2: Q=8.8 l/s=2 Q₂ (Q₂=4.4 l/s from rooms 1&3)</p> <p>Room 3: Q₁= 4.4l/s (outdoor air)</p> <p>Room 4: Q= 8.8l/s (outdoor air)</p> <p>Average T= 28± 0.6 ° C</p> <p>Average RH = 48± 2 %</p>
<u>Experiment 3</u>			
Part 1	<p><u>Room 1</u>: carpet (14 m²)</p> <p><u>Room 2</u>: painted gypsum board (23 m²)</p> <p><u>Rooms 3</u>: carpet and painted gypsum board (14 m²+23m²)</p>	Assessments performed for the empty rooms then 4, 24, 48, 72, 96, and 168 hrs after the materials were placed inside the rooms	<p>Ventilation rate:</p> <p>Room1: Q = 8.8l/s (outdoor air)</p> <p>Room 2: Q =8.8l/s (outdoor air)</p> <p>Room 3: Q= 8.8l/s (outdoor air)</p> <p>Average T= 25± 0.6 ° C</p> <p>Average RH = 50± 3 %</p>
Part 2	<p><u>Room 1</u>: empty</p> <p><u>Room 3</u>: painted gypsum board (23m²)</p>	Assessments performed for room 1 and room 3 4, 24 and 48 hrs after taking the carpet out of the rooms	<p>Average T=22.6± 0.4 °C</p> <p>Average RH = 50± 3 %</p>

	Test materials	Sensory assessments	Experiment conditions
<u>Experiment 4</u>	<u>Room 1</u> : carpet (14 m ²) <u>Room 2</u> : virgin gypsum board (23 m ²) <u>Room 3</u> : carpet and virgin gypsum board (14 m ² +23 m ²)	Assessments performed for the empty rooms then after 4, 24, 48, 72, 96, and 168 hrs of placing the materials inside the rooms	Ventilation rate: Room 1: Q = 8.8 l/s (outdoor air) Room 2: Q = 8.8 l/s (outdoor air) Room 3: Q = 8.8 l/s (outdoor air) Average T = 24.6±0.6 °C Average RH = 50± 3 %
<u>Experiment 5</u>			
Part 1	<u>Room 1</u> : Linoleum (14 m ²) <u>Room 2</u> : painted gypsum board (23 m ²) <u>Room 3</u> : Linoleum and painted gypsum board (14 m ² +23m ²)	Assessments performed for the empty rooms then after 4, 24, 48, 72, 96, and 168 hrs of placing the material inside the rooms	Ventilation rate: Room 1: Q = 8.8 l/s (outdoor air) Room 2: Q = 8.8 l/s (outdoor air) Room 3: Q = 8.8 l/s (outdoor air)
Part 2	<u>Room 1</u> : empty <u>Room 3</u> : Painted gypsum board (23 m ²)	Assessments performed for room 1 and room 3 after 4, 24, 48 and 72 hrs of taking the linoleum out of the rooms	Preset T and RH (for both parts): T = 22° C RH = 40 %
<u>Experiment 6</u>			
Part 1	<u>Room 1</u> : Linoleum (14 m ²) <u>Room 2</u> : Semia (24.5 m ²) <u>Room 3</u> : Linoleum+Semia (14 m ² +24.5m ²)	Assessments performed for the empty rooms then after 4, 24, 48, 72, 96, and 168 hrs of placing the material inside the rooms	Ventilation rate: Room 1: Q = 8.8 l/s (outdoor air) Room 2: Q = 8.8 l/s (outdoor air) Room 3: Q = 8.8 l/s (outdoor air)
Part 2	<u>Room 1</u> : empty <u>Room 3</u> : Semia (24.5 m ²)	Assessments performed for room 1 and room 3 after 4, 24, 48 and 72 hrs of taking the linoleum out of the room	Preset T and RH (for both parts): T = 22° C RH = 40 %

	Test materials	Sensory assessments	Experiment conditions
<u>Experiment 7</u>	<u>Room 1</u> : carpet (14 m ²) <u>Room 2</u> : exhaust air from rooms 1&3 <u>Rooms 3</u> : painted gypsum board (23 m ²) <u>Rooms 4</u> : carpet and painted gypsum board (14 m ² +23m ²)	Assessments performed for the empty rooms then after 4,8, 24,48, 72, and 144 hrs of placing the materials inside the rooms	Ventilation rate: Room 1: $Q_1 = 4.4 \text{ l/s}$ (outdoor air) Room 2: $Q = 8.8 \text{ l/s} = 2 Q_2$ ($Q_2 = 4.4 \text{ l/s}$ from rooms 1&3) Room 3: $Q_1 = 4.4 \text{ l/s}$ (outdoor air) Room 4: $Q = 8.8 \text{ l/s}$ (outdoor air) Preset T and RH (for both parts): T = 22° C, RH =35 %

To allow mixing the exhaust air from the two other adjacent rooms, two holes in the two opposite walls were equipped by two axial fans and dampers. By changing the velocity of the fans and the position of the damper the air exchange rate between the rooms was controlled. The supply air to this room (mixing room) was solely from the two adjacent rooms. The outdoor air was supplied to the other three rooms by ventilation systems, located in each room, consisting of an axial fan mounted to the window and a damper to control the flow. The outdoor air was neither filtered nor conditioned. To assure that all the outdoor air supply to the rooms, where individual materials were placed, is transferred to the mixing room in the middle, the gap under the doors in these two rooms was sealed so no airflow from or to the corridor could occur. The air from the other two offices was exhausted through the gap underneath the door to the corridor. Small fans were distributed in the four offices to ensure that the air was well mixed. Each office had a screen, which served to hide the test materials from the panel's view.

3.1.3 Building materials

Samples of carpet, painted gypsum board, virgin gypsum board, linoleum and Semia were used in these experiments. The carpet was approximately 24 years old, taken from an office building. The gypsum board was painted (on both sides) six months before the experiment. The linoleum was 5 years old. Virgin gypsum board was new and it had been received one month before the initial experiment. Semia is absorbing sheets consisting of fine activated charcoals particles embedded between polyester-filament non-woven layers. The Semia was delivered three months before the experiments took place and it was kept in its original package until it was used. The carpet and linoleum samples were stapled back to back to reduce emission from the backside and they were hung on stainless steel racks when placed behind the screen in the rooms. The size of material samples was determined assuming that the office floor (used in this experiment) is covered with carpet or linoleum (wall to wall) and the walls were made of painted gypsum boards.

3.1.4 Sensory Panel

Untrained panels, composed of different numbers of subjects randomly chosen from students and employees at the center, took part in these experiments. See Table 3.2 for data concerning the panel for each experiment. For experiments 1, 2, 3 and 4 the participants were volunteers while thirty-one students were recruited to participate in experiments 5 and 6, and thirty-four recruited students participated in experiment 7. Before the start of the experiments, the panel was carefully instructed on how to use the acceptability scale (See Figure 3.2), and it was pointed out that focus should be on the

initial perception and that no communication on air quality is allowed during the assessments. They were asked not to eat spicy food or garlic on the experiment day and the day before, and not to use strong deodorant the day of the experiment.

3.1.5 Procedure

Seven experiments were performed during a one-year period. Each experiment lasted between one week (for experiments aimed to study adsorption stage only) and ten days (for experiments that studied adsorption and desorption stages). Sensory assessments took place every day except on weekends. Before each experiment the rooms were cleaned and ventilated for 48 hrs at a high air exchange rate.

Table 3.2 Data on participating subjects

Experiment	Number of subjects	Average age \pm Standard deviation (years)	Males %	Smokers %
Experiment 1	16	29.5 ± 7.3	53	13
Experiment 2	15	28.2 ± 6.9	67	13
Experiment 3	18	30.6 ± 8.1	61	11
Experiment 4	18	30.6 ± 8.1	61	11
Experiment 5	31	24.7 ± 4.3	74	10
Experiment 6	31	24.7 ± 4.3	74	10
Experiment 7	34	25.1 ± 5.1	70	6

Then the air exchange rate was adjusted using tracer gas (SF₆) decay method measurements (Kjaer Multi-gas monitor 1302 and Multipoint sampler and Doser 1303).

See Table 3.1 for ventilation rate for each room and each experiment. The air exchange

rate was chosen to be rather low to maximize the impact of sorption. The same samples of materials (carpet, linoleum, painted gypsum board) were used in all experiments.

Before the start of experiments (except experiment1), the material samples were ventilated for 48 hrs in two different places with high supply rate of outdoor air so the materials could get rid of what might have been previously adsorbed on their surfaces.

Before the materials were introduced to the rooms, the sensory panel assessed the air quality for the empty rooms. Sensory evaluation followed a time schedule that was preset for each experiment (see Table 3.1). The sensory panel assessed the air quality of the offices using a continuous acceptability scale shown in Figure 3.2. Sensory assessments were performed according to a randomized plan that was different for different subjects and different days of the experiment.

Name:	Room :
Date:	

Imagine that during your daily work you are exposed to this air.

How do you assess the air quality?

Notice the distinction between acceptable and unacceptable

Clearly acceptable

Just acceptable

Just unacceptable

Clearly unacceptable

Figure 3.2. Acceptability scale

The subjects were unaware of the experimental conditions in the rooms where they assessed the air quality. Only one participant at a time was allowed to enter the same room for sensory assessments. Subjects were asked to keep two minutes interval between one assessment and the other. For experiments 5, 6 and 7 and between the sensory evaluations of the rooms, the panel was seated in an office next to the offices used in these experiments. This office was naturally ventilated and the windows were kept open to assure the freshness of its air. After each assessment, the participating subjects were asked to spend two minutes in this room before proceeding to the next assessment. Temperature and relative humidity were measured during all experiments and they were controlled in experiments 5, 6 (T= 22 °C, RH= 40 %) and experiment 7 (T= 22 °C, RH= 35 %) by electrical heaters and ultrasonic humidifiers.

3.1.6 Calculation of Sensory Pollution Loads

The assessments of acceptability of the air in the offices were used to calculate perceived air quality in decipol and the sensory pollution loads expressed in olf units. The subjects were asked to do the assessments by marking on the acceptability scale. Numbers were assigned to the marks: clearly acceptable = 1, clearly not acceptable = -1, just acceptable/just not acceptable=0 and any mark in between was considered to belong to a linear scale. Then the mean acceptability votes were calculated for the whole panel and used to find the percentage of dissatisfied people (Gunnarsen and Fanger, 1992), from which, the perceived air quality in decipol (Fanger, 1988) was found using the following equations:

$$PD = \left[\frac{\exp(-0.18 - 5.28 \cdot \text{Acc.})}{1 + \exp(-0.18 - 5.28 \cdot \text{Acc.})} \right] 100 \dots\dots\dots (3.1)$$

Acc.= mean acceptability vote

$$C = 112 (\ln (PD) - 5.98)^{-4} \dots\dots\dots (3.2)$$

PD = percentage of dissatisfied (%)

C = perceived indoor air quality in (decipol)

The perceived air quality (in decipol) and the measured ventilation rate can then be applied in the comfort equation (Fanger, 1989) to find the sensory pollution load in the studied space expressed in olfs.

$$G = 0.1 Q (C - C_o) \dots\dots\dots (3.3)$$

G = sensory pollution loads in olf

Q = measured outdoor air supply to the room L/s

C = perceived indoor air quality (decipol)

C_o= perceived air quality of outdoor air (decipol), in this study C_o is the perceived air quality of the empty room (background)

3.1.7 Statistical Analysis

In this study, which is based on data obtained from sensory assessments of human subjects, the non-parametric statistical tests are more convenient than the parametric tests due to the small size of samples and the unknown distribution of the population. In behavioral science where data rarely satisfy the assumption of parametric test (normal distribution for the population) and where it could be categorized only as plus or minus (better or worse) a nonparametric statistical test is superior in power to a parametric one (Siegle and Castellan 1988).

Wilcoxon Matched Pairs Test, a non-parametric test, was used to compare two paired

groups of the data obtained from sensory assessments of acceptability of the air in the studied offices. To compare more than two groups Friedman's two-way analysis of variance test, another nonparametric test, was used. The results of statistic analyses for all experiments are presented in Appendix A.

3.2 Results

3.2.1 Carpet and painted gypsum board

Four experiments were performed using carpet and painted gypsum board as test materials. The aim was to investigate the impact on perceived air quality of having the two materials (carpet & painted gypsum board) together in one room in comparison to the case where the air is polluted by only one of these two materials (carpet or painted gypsum board). In other words, to study the interaction between the indoor material surfaces and the impact on perceived air quality. Sensory assessments for the air in the mixing room, experiments 2 and 7, aimed to isolate the impact of sorption on the room surfaces from the impact of sorption on the test building materials surfaces. This was done so that the interaction between the pollutants emitted from the test building materials and the room surfaces could be investigated. The results of the sensory assessments for these experiments, expressed in terms of acceptability, perceived air quality (decipol) and pollution loads (olf) together with the environmental conditions during all assessments are presented in Tables 3.3, 3.4, 3.5 and 3.6.

3.2.1.1 Experiment 1:

A sensory panel of an average of 15 subjects assessed the acceptability of the air in three

similar offices where the air was polluted either by individual materials or by a combination of two materials. The average standard error of all acceptability votes was ± 0.1 . Assessments were performed first for the empty rooms, then after 4, 24 and 120 hrs of placing the materials inside the rooms. The air exchange rate was equal to 0.8 ± 0.05 in all the rooms. The average measured temperature and relative humidity of the three rooms during each assessment are shown in Table 3.3. The results show that perceived air quality improved significantly when carpet and painted gypsum board were placed together in a room in comparison with the case where the air was polluted by carpet alone ($P < 0.001$, four hours after the materials were placed together and $P < 0.01$ after 24 hours). Acceptability assessments performed four hours after the materials were placed inside the room showed that the air of the room with the two materials was perceived not only better than the carpet alone but even better than the painted gypsum board. The level of improvement decreased with time, and the perceived air quality for combined materials approached that of the carpet alone. The difference between the conditions was no longer significant ($P = 0.7$) after 120 hrs. Painted gypsum board was perceived to be almost the same during all assessments. Figure 3.3 shows the mean acceptability votes for the three different rooms. Assessments performed four hrs after the materials were placed inside the rooms indicated a low acceptability of the air polluted by carpet alone (Acc. = -0.46, PD = 90%). This is believed to be due to pollutants that may have been adsorbed on the carpet surface when it was stored in the same place as other polluting materials. This assumption could also explain the big improvement of the air quality polluted by carpet when it was assessed again 24 hrs latter, and the deterioration in perceived air quality in the room with combination of two materials after 120 hrs when the sink is full and no

Table 3.3. Perceived air quality and environmental conditions during all assessments of Experiment 1

Time (hrs)*	Acceptability±Standard error			Percentage dissatisfied (%)			Perceived air quality (decipol)			Pollution load (olf)			Environmental conditions ± Standard deviation	
	Carpet	Painted gypsum Board	Carpet& painted gypsum board	Carpet	Painted gypsum board	Carpet & painted gypsum board	Carpet	Painted gypsum Board	Carpet & painted gypsum board	Carpet	Painted gypsum Board	Carpet & painted gypsum board	T °C	RH %
<u>Exper.(1)</u>														
Empty rooms	0.2± 0.09	0.36±0.11	0.43±0.09	22.5	11.1	7.9	1.7	0.7	0.5	1.5	0.6	0.4	24± 0.8	43±3
4	-0.46±0.07	0.05±0.1	0.13±0.11	90.5	39.0	30.0	23.7	3.9	2.5	20.8	3.4	2.2	24± 0.8	42± 3
24	-0.29±0.08	0.04±0.11	0.05±0.1	79.4	40.3	39.1	16.9	4.1	3.9	14.8	3.6	3.4	23± 0.8	35±3
120	-0.28±0.11	0.06±0.11	-0.24±0.1	78.6	37.8	74.8	16.4	3.7	14.6	14.4	3.2	12.8	24± 0.7	33±3

more pollutant could be adsorbed.

For the experiments performed later on, in order to overcome this complication, the material samples to be tested were ventilated in isolation for 48 hrs before they were used in the experiments.

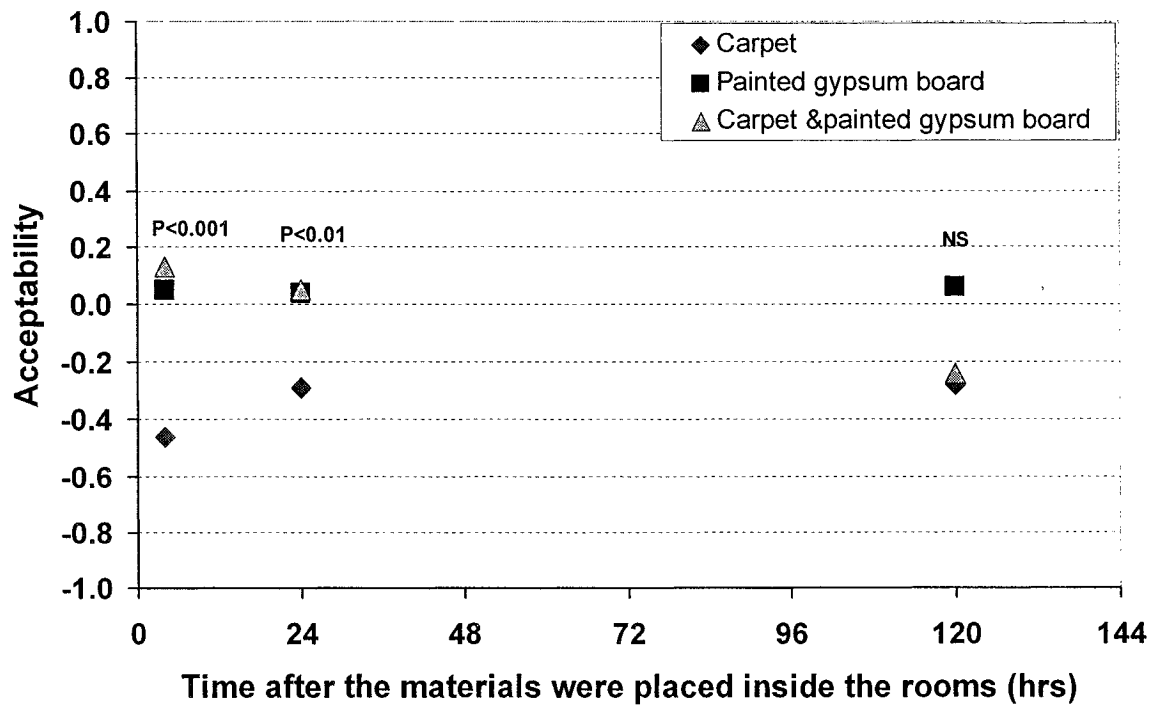


Figure 3.3. Mean assessments of acceptability of air polluted by carpet, painted gypsum board and by combination of carpet and painted gypsum board

It might be useful to point out that the results of assessments in the mixing room were not considered valid due to a mistake in the experimental design. As shown in Table 3.1 the mixing room took air only from the two adjacent rooms that contained samples of carpet or painted gypsum board (4.4 l/s from each room), which means only half of the outdoor ventilation rate to each adjacent room was transferred to the mixing room. This resulted in overestimation of the impact of mixing, as the concentration in the mixing room would be half of the sum of the concentrations in the adjacent rooms. This was corrected in the

other mixing experiments performed later on , Experiment 2 and Experiment 7.

3.2.1.2 Experiment 2

Samples of carpet and painted gypsum board were tested individually, as a combination of the two materials, and for the case when the air polluted by these two materials was mixed in another room. A sensory panel consisting of 15 subjects assessed the acceptability of the air in the four rooms. Assessments were performed first for the empty rooms then after 4, 8, 24, 48, 72, 144 and 168 hrs. The average standard error for all assessments was ± 0.1 (mean standard deviation of ± 0.36). The results from the sensory assessments and the average measured temperatures and relative humidities for the four rooms during each assessment session are presented in Table 3.4. The mean votes of acceptability for the air in the four rooms and the level of significance between assessments performed in the room with carpet and the room with carpet and painted gypsum board are shown in Figure 3.4.

The results, in general, showed a low acceptability of the air in the four rooms during all assessment sessions. However, an improvement of perceived air quality in the mixing room and in the room that contained both materials (carpet and painted gypsum board) in comparison with the perceived air quality of the air polluted by carpet alone was observed during the one week experimental period. In this experiment the participating subjects were not the same for all assessments, hence a comparison of acceptability assessments could only be conducted for assessments performed at the same sensory session and not for different sessions performed at different times.

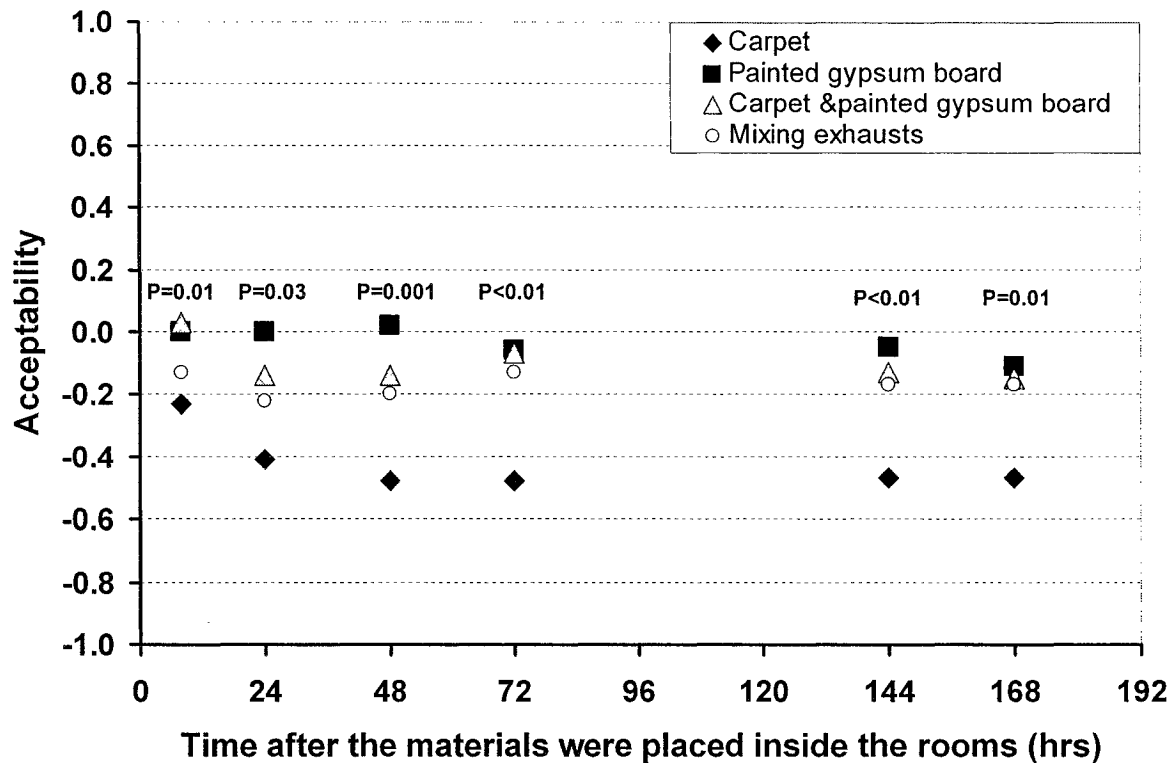


Figure 3.4 Mean assessments of acceptability for air in the rooms that contained carpet, painted gypsum board, carpet and painted gypsum board together and for the room where the exhaust air from the rooms with carpet and painted gypsum board were mixed.

The temperature was relatively high during the whole experiment. Based on the results of Fang et al (1998), this would be expected to adversely affect the perceived air quality. It might also increase the emission rate of selected pollutants and decrease the sorption to room surfaces. Hence, the low acceptability of the air observed in all the rooms during this experiment is consistent with expectations. As mentioned earlier, the results showed that perceived air quality improved for the cases when carpet and painted gypsum board were placed together in the same room, and when air polluted by both materials was mixed in another room (without the materials themselves). One contributing factor to this

Table 3.4. Perceived air quality and environmental conditions during all of the assessments performed during Experiment 2

Time (hrs)*	Acceptability				Percentage dissatisfied				Perceived air quality (decipol)				Pollution load (olf)				Environmental conditions \pm Standard deviation	
	1 Carpet	2 Painted gypsum board	3 Carpet+ painted gypsum board	4 Mixing exhausts	1	2	3	4	1	2	3	4	1	2	3	4	T °C	RH %
Exper. (2)																		
Empty Rooms	0.3 \pm 0.07	0.28 \pm 0.07	0.4 \pm 0.09	0.25 \pm 0.07	14.6	16	9.2	18.2	0.9	1.1	0.6	1.25	0.8	0.9	0.5	1.1	29.2 \pm 0.24	47 \pm 3
4	-0.34 \pm 0.08	-0.07 \pm 0.09	-0.13 \pm 0.07	-0.1 \pm 0.09	83.4	54.7	62.4	58.6	19.1	7.3	9.6	8.4	16.8	6.4	8.5	7.4	28.2 \pm 0.2	48 \pm 3
8	-0.23 \pm 0.1	0 \pm 0.06	0.03 \pm 0.1	-0.13 \pm 0.1	73.8	45.5	41.6	62.4	14.1	5.1	4.4	9.6	12.4	4.5	3.8	8.5	28.5 \pm 0.2	46 \pm 2
24	-0.41 \pm 0.12	0 \pm 0.08	-0.14 \pm 0.14	-0.22 \pm 0.11	87.9	45.5	63.6	72.7	21.9	5.1	10.1	13.6	19.3	4.5	8.8	12.0	28.5 \pm 0.2	46 \pm 2
48	-0.48 \pm 0.09	0.02 \pm 0.1	-0.14 \pm 0.1	-0.2 \pm 0.1	91.3	42.9	63.6	70.6	24.3	4.6	10.1	12.7	21.4	4.1	8.8	11.2	28.4 \pm 0.4	49 \pm 2
72	-0.48 \pm 0.1	-0.06 \pm 0.08	-0.07 \pm 0.12	-0.13 \pm 0.1	91.3	53.4	54.7	62.4	24.3	7.0	7.3	9.6	21.4	6.1	6.4	8.5	28.5 \pm 0.4	49 \pm 2
144	-0.47 \pm 0.09	-0.05 \pm 0.12	-0.13 \pm 0.1	-0.17 \pm 0.1	90.9	52.1	62.4	67.2	24.0	6.6	9.6	11.4	21.1	5.8	8.5	10.0	27.6 \pm 0.4	49 \pm 2
168	-0.47 \pm 0.09	-0.11 \pm 0.09	-0.15 \pm 0.16	-0.17 \pm 0.1	90.9	59.9	64.8	67.2	24.0	8.8	10.5	11.4	21.1	7.8	9.2	10.0	27.3 \pm 0.4	47 \pm 2

- 1: the room with carpet samples
- 2: the room with painted gypsum board samples
- 3: the room with combination of the two materials i.e. carpet and painted gypsum board
- 4: the mixing room where the exhaust air from the two adjacent rooms with carpet or painted gypsum board were mixed

result could be that the air change rate was 0.4 h^{-1} in the rooms with individual materials while it was 0.8 h^{-1} in the other two rooms. Another contributing factor, believed to be more important, is the impact of sorption. Figure 3.4 shows that perceived air quality improved when exhaust air polluted by the two individual materials was mixed in a third room ($P=0.01$). This improvement is presumably due to the impact of sorption. When pollutants emitted from carpet and painted gypsum boards were transferred to the mixing room, some of them were adsorbed on its surfaces. Further improvement, in comparison with the case of mixing exhausts, was observed when the two materials were placed in the same room. This is presumably due to sorption on the material surfaces.

The relatively high temperature during all assessments could be behind the observed low impact of sorption. According to previous studies, at high temperatures sorption is less (Tichenor et al 1991, Van der Wal et al. 1998).

3.2.1.3 Experiment 3

In this experiment, the impact of desorption was investigated in addition to the impact of sorption. Sensory assessments for air polluted by carpet or painted gypsum board or by a combination of both were performed during a one-week period. Later on, the carpet was taken out of the rooms and the sensory panel assessed the air of an empty room and a room with painted gypsum board (both of which had carpet in the first part of the experiment). The results of this experiment are presented in Table 3.5 and Figure 3.5. The level of significance for assessments performed in the room with carpet and the room with carpet and painted gypsum board are shown in Figure 3.5.

The results show that the air polluted by both materials (carpet and painted gypsum board) was perceived better than that in the room polluted by carpet alone, but less acceptable than the air polluted by painted gypsum board. The improvement was observed for all six assessments, although statistical analysis did not show the same level of significance for all assessments (see Figure 3.5). A big improvement in perceived air quality was observed soon after the carpet was taken out of the rooms. However, it was only after three days that the air in the rooms that contained carpet in the first part of the experiment (i.e., the empty room and one polluted only by painted gypsum board), could be perceived as though the carpet was never there.

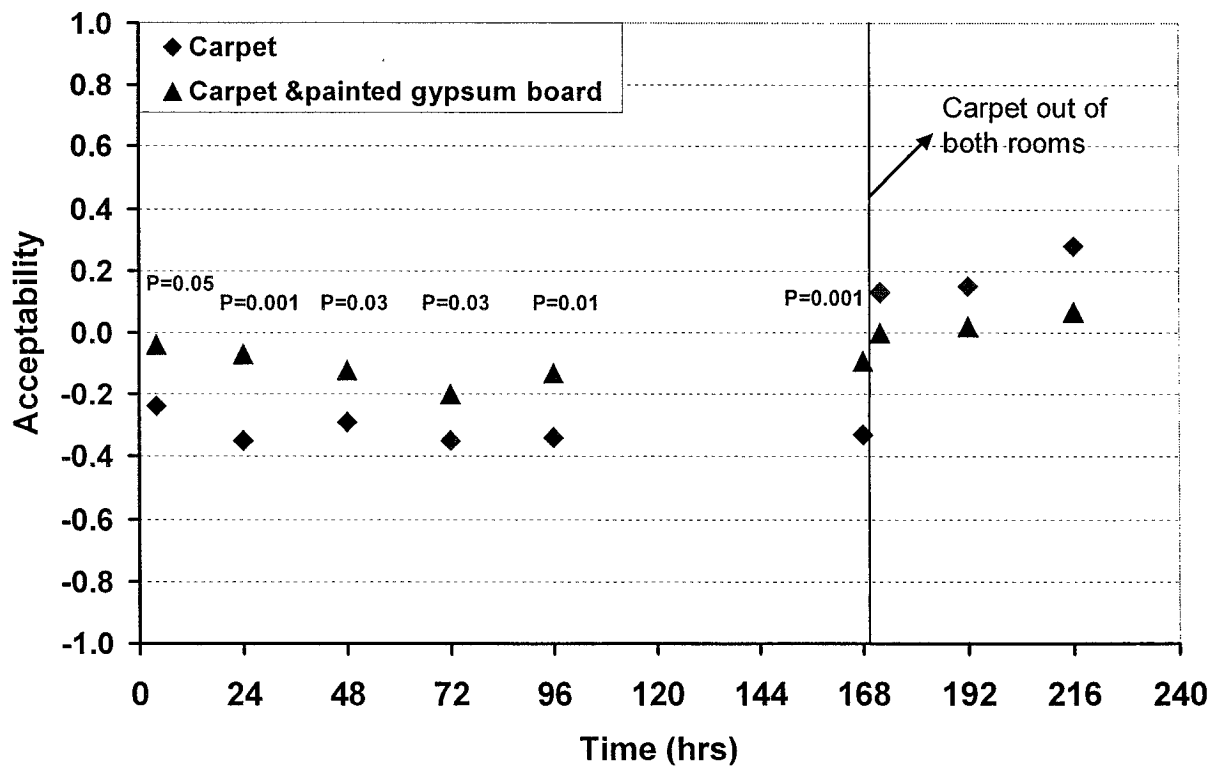


Figure 3.5. Mean assessments of acceptability of air polluted by carpet, painted gypsum board and by a combination of carpet and painted gypsum board. Included are assessments that were made after the carpet was taken out.

Table 3.5. Perceived air quality and environmental conditions during all of the assessments performed during Experiment 3.

Time (hrs)*	Acceptability±Standard error			Percentage dissatisfied (%)			Perceived air quality (decipol)			Pollution load (olf)			Environmental conditions ± Standard deviation	
	Carpet	Painted gypsum Board	Carpet& painted gypsum board	Carpet	Painted gypsum board	Carpet& painted gypsum board	Carpet	Painted gypsum Board	Carpet & painted gypsum board	Carpet	Painted gypsum Board	Carpet & painted gypsum board	T °C	RH %
<u>Exper. (3)</u>														
Empty room	0.44±0.09	0.43±0.09	0.2±0.10	8.0	8.0	23.0	0.5	0.5	1.7	0.4	0.4	1.5	25±0.6	45±3
<u>Part 1</u>														
4	-0.24±0.07	0.05±0.09	-0.04±0.11	75.0	39.1	51.0	14.6	3.9	6.3	12.8	3.4	5.5	25±0.4	59±3
24	-0.35±0.09	0.11±0.10	-0.07±0.11	84.1	31.8	55.0	19.5	2.8	7.3	17.2	2.4	6.4	25±0.4	56±3
48	-0.29±0.11	0.05±0.10	-0.12±0.09	79.4	39.1	61.1	16.9	3.9	9.2	14.8	3.4	8.1	25±0.4	51±3
72	-0.35±0.11	0.00±0.10	-0.20±0.09	84.1	45.5	70.6	19.5	5.1	12.7	17.2	4.5	11.2	25±0.8	46±3
96	-0.34±0.11	0.10±0.07	-0.13±0.09	83.4	33.0	62.4	19.1	2.9	9.6	16.8	2.6	8.5	25±0.8	51±3
168	-0.33±0.10	-0.02±0.09	-0.09±0.10	82.7	48.1	57.3	18.7	5.7	8.1	16.4	5.0	7.1	23±0.4	37±3
<u>Part 2**</u>														
Carpet out	Empty	Painted gypsum board												
172	0.13±0.16	0.00±0.14		29.6		45.5	2.5		5.1	2.18		4.5	23±0.4	40±3
192	0.15±0.14	0.02±0.16		27.4		42.9	2.2		4.6	1.95		4.1	23±0.4	50±3
216	0.28±0.13	0.07±0.16		16.0		36.6	1.1		3.5	0.93		3.1	22±0.3	52±3

* Time after the materials were placed inside the rooms

** In this part of experiment only assessments performed by the same subjects (10 subjects) were considered to allow comparison between assessments.

This result could be explained by adsorption (on the rooms and painted gypsum board surfaces) that took place when the carpet was in the room. As soon as the carpet was taken out of the room, the drop in concentration initiated the desorption process, and it took three days to desorb the emissions that had adsorbed to these surfaces. Before the start of this experiment the carpet and painted gypsum board were ventilated separately for 48 hrs in rooms with a high supply rate of outdoor air to get rid of what might have been adsorbed on their surfaces during the storage time. In this experiment the temperature was relatively high (average temperature= $25 \pm 0.4^{\circ} \text{C}$) which might have affected the perception of the assessed air to be less acceptable (Fang et al 1998), but temperature and relative humidity, measured on the day of the assessments, were the same for the different rooms.

The panel participating in this experiment consisted of an average of 18 subjects, seven of which participated in all the assessments, while the others were different throughout. As this and the impact of changing temperature and relative humidity during the one-week experiment could lead to errors when comparing assessments performed on different days, in this experiment it is only valid to compare assessments performed on the same day.

3.2.1.4 Experiment 7

A larger panel of thirty-four recruited subjects participated in this experiment (a total of 30 attended all assessments) for which the environmental conditions (temperature and relative humidity), were controlled. Before the start of the experiment, the temperature and relative humidity were set at $T = 22^{\circ}\text{C}$ and $\text{RH} = 35\%$, the measured temperature and relative humidity during all sensory sessions are shown in Table 3.6. The same carpet

and painted gypsum board used in the previous experiments were used in this experiment too. Before the start of the experiment the two test materials were ventilated separately for 48 hrs in two different places with high supply rate of outdoor air to clean the materials from any pollutants that might be adsorbed previously. The air exchange rate fixed to be 0.4 h^{-1} for two rooms where carpet and painted gypsum board were being tested individually and 0.8 h^{-1} for the other two rooms, one where the air polluted by the two individual materials was mixed and the other is for the room used for testing combination of carpet and painted gypsum board. See Table 3.1 for the experimental design. The results of acceptability assessments for the four rooms during the one-week experiment are presented in Figure 3.6 and Table 3.6.

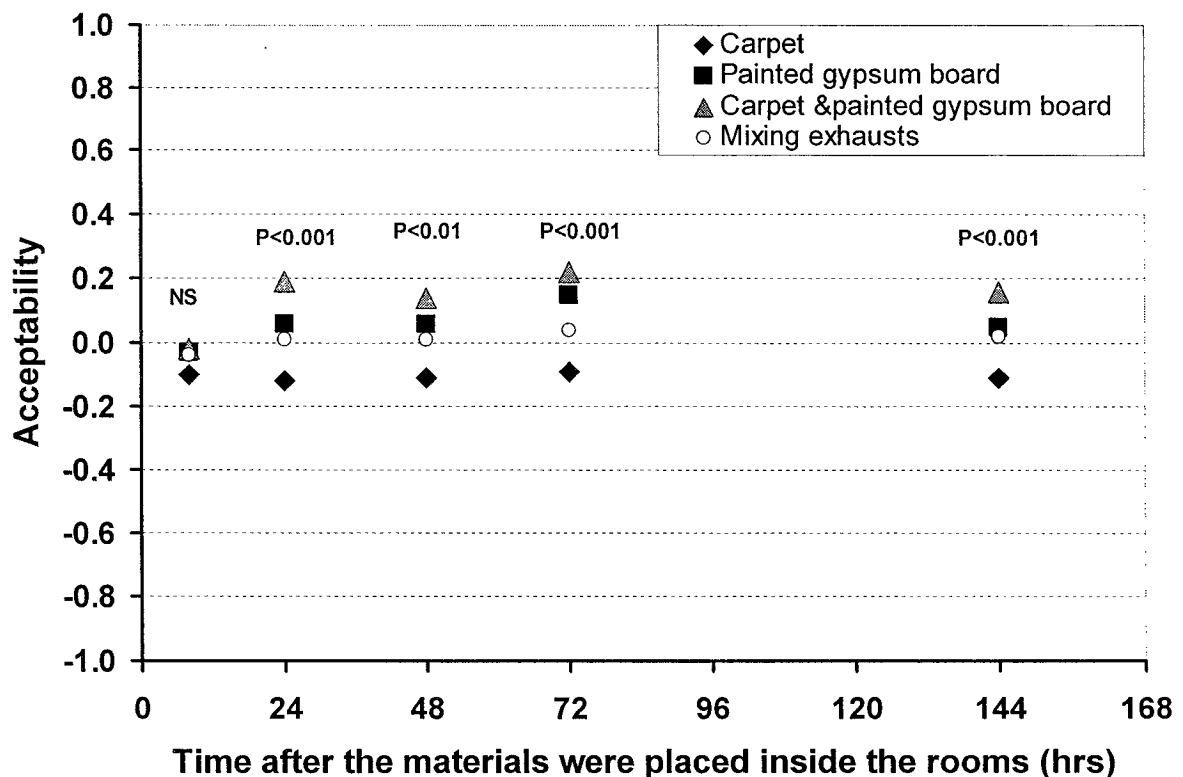


Figure 3.6 Mean assessments of acceptability for the air in the rooms that contained carpet, painted gypsum board, carpet and painted gypsum board together and for the room where the exhaust air from the rooms with carpet and painted gypsum board were mixed.

Table 3.6. Perceived air quality and environmental conditions during all of the assessments performed during Experiment 7.

Acceptability				Percentage dissatisfied				Perceived air quality (decipol)				Pollution load (olf)				Environmental conditions ± Standard deviation		
Time (hrs*)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	T °C	RH %
Exper. (\bar{x})																		
Empty Rooms	0.27±0.06	0.27±0.06	0.32±0.07	0.25±0.06	16.7	16.7	13.3	18.2	1.1	1.1	0.85	1.25	1	0.7	1.1	22±0.1	36±2	
4	-0.03±0.09	0.02±0.07	0.02±0.08	0.06±0.07	49.5	42.9	42.9	37.8	6.0	4.6	4.6	3.7	5.3	4.1	4.1	22 ± 0.1	36 ± 2	
8	-0.10±0.08	-0.03±0.06	-0.02±0.07	-0.04±0.06	59.0	49.0	48.0	51.0	8.4	6.0	5.69	6.31	7.4	5.28	5.01	22.1± 0.1	36 ± 2	
24	-0.12±0.07	0.06±0.07	0.19±0.07	0.01±0.08	61.1	37.8	23.4	44.2	9.2	3.7	1.8	4.9	8.1	3.2	1.6	22.1 ± 0.1	36 ± 2	
48	-0.11±0.07	0.06±0.07	0.14±0.07	0.01±0.07	59.9	37.8	28.5	44.2	8.8	3.7	2.3	4.9	7.8	3.2	2.1	22.4 ± 0.2	36 ± 2	
72	-0.09±0.08	0.15±0.07	0.22±0.06	0.04±0.08	57.3	27.4	20.7	40.3	8.1	2.2	1.5	4.1	7.1	1.9	1.3	22.4 ± 0.3	37 ± 2	
144	-0.11±0.08	0.05±0.07	0.16±0.08	0.02±0.09	59.9	39.1	26.4	42.9	8.8	3.9	2.1	4.6	7.8	3.4	1.8	22.3 ± 0.3	36 ± 2	

- 1: the room with carpet samples
2: the room with painted gypsum board samples
3: the room with combination of the two materials i.e carpet and painted gypsum board
4: the mixing room where the exhaust air from the two adjacent rooms with carpet or painted gypsum board were mixed

The average standard error for all assessments performed in this experiment was ± 0.07 and the mean standard deviation was ± 0.41 . The results show that the air in the room that had the combination of two materials was perceived to be the best among the four rooms and thus during the whole experiment. As shown in Figure 3.6 the acceptability of the air polluted by both materials placed in the same room was better than the air polluted by carpet alone ($P < 0.01$) or painted gypsum board alone. This suggests that both materials are acting as pollution source and sink at the same time. The air quality improved when air polluted by carpet or gypsum board was mixed in a third room, in comparison with the air polluted by carpet alone, an improvement, which is referred to the impact of sorption on the room surfaces.

The further improvement when carpet and painted gypsum boards are placed together in the same room is mainly due to sorption on the test material surfaces. In this experiment the results show that the sorption has a significant impact on perceived air quality even after 144 hrs ($P < 0.001$), which might be resulted from using cleaner materials surfaces as a result of the pre-ventilation.

3.2.2 Carpet and virgin gypsum board

3.2.2.1 Experiment 4

This experiment was conducted using the same sensory panel as Experiment 3. Sensory assessments for the air quality in rooms that contained virgin gypsum board alone and for combination of carpet and virgin gypsum boards were performed during one week and the results are presented in Table 3.7 and Figure 3.7.

The average standard error for all acceptability assessments performed in this experiment

was ± 0.1 and the mean standard deviation was ± 0.41 . For all assessments, the air polluted by carpet and virgin gypsum board was perceived better than the air polluted by carpet alone. However, no statistically significant improvement was noticed except for the assessment performed after 24 hrs of placing the two materials together ($P=0.04$).

The relatively small improvement in perceived air quality may be due to the fact that the virgin gypsum board alone was perceived to be much less acceptable compared to the painted gypsum board, the reason could be that virgin gypsum board used in this experiment was new while painted gypsum board was painted 6 months before the experiment.

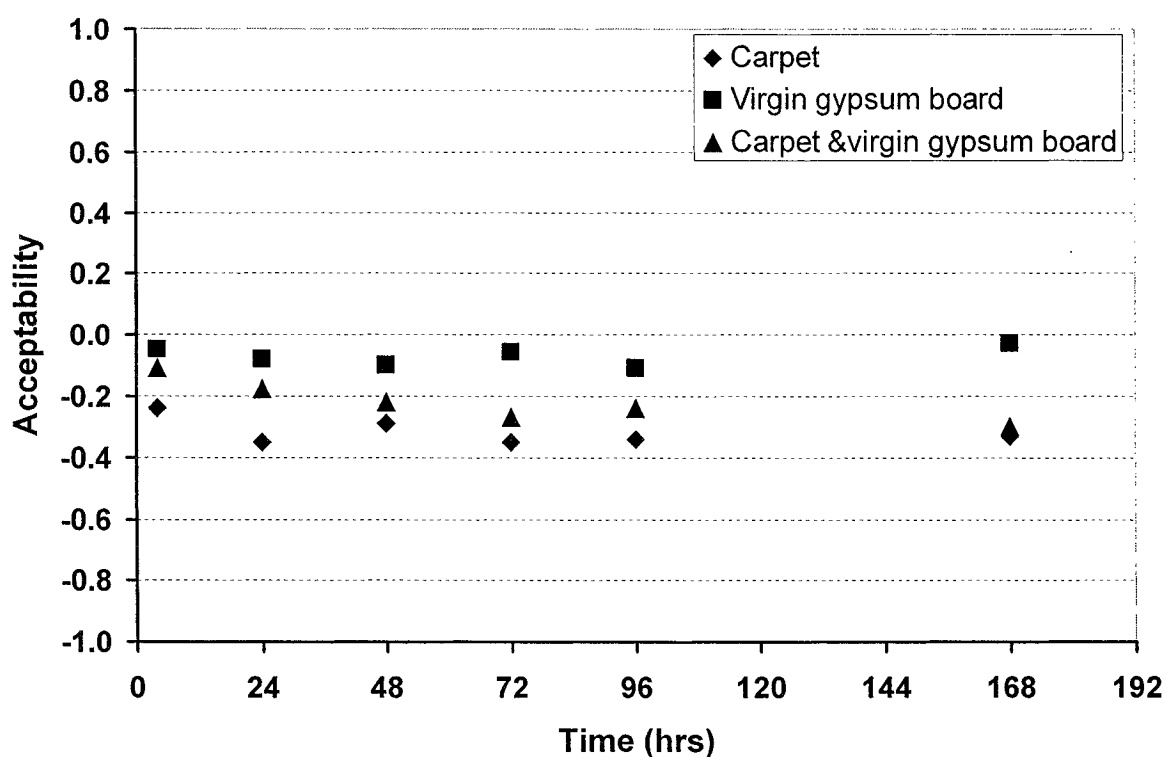


Figure 3.7. Mean assessments of acceptability of air polluted by carpet, virgin gypsum board and by a combination of carpet and virgin gypsum board.

Table 3.7. Perceived air quality and environmental conditions during all of the assessments performed during Experiment 4.

Time (hrs)*	Acceptability			Percentage dissatisfied			Perceived air quality (decipol)			Pollution load (olf)			Environmental conditions \pm Standard deviation	
	Carpet	Virgin gypsum Board	Carpet & virgin gypsum board	1	2	3	1	2	3	1	2	3	T °C	RH %
<u>Exper. (4)</u>														
Empty	0.44 \pm 0.09	0.26 \pm 0.1	0.31 \pm 0.09	8.0	17	14	0.5	1.2	0.9	0.4	1.0	0.8	25 \pm 0.6	45 \pm 3
4	-0.24 \pm 0.07	-0.05 \pm 0.07	-0.11 \pm 0.1	75.0	52.1	59.9	14.6	6.6	8.8	12.8	5.8	7.8	25 \pm 0.4	59 \pm 3
24	-0.35 \pm 0.09	-0.08 \pm 0.08	-0.18 \pm 0.1	84.1	56.0	68.4	19.5	7.7	11.8	17.2	6.8	10.4	25 \pm 0.4	56 \pm 3
48	-0.29 \pm 0.11	-0.1 \pm 0.08	-0.22 \pm 0.07	79.0	58.6	72.7	16.9	8.4	13.6	14.9	7.4	12.0	25 \pm 0.4	51 \pm 3
72	-0.35 \pm 0.11	-0.06 \pm 0.12	-0.27 \pm 0.1	84.1	53.4	77.7	19.5	7.0	16.0	17.2	6.1	14.0	25 \pm 0.8	46 \pm 3
96	-0.34 \pm 0.1	-0.11 \pm 0.1	-0.24 \pm 0.09	83.4	59.9	74.8	19.1	8.8	14.6	16.8	7.8	12.8	25 \pm 0.8	51 \pm 3
168	-0.33 \pm 0.1	-0.03 \pm 0.13	-0.3 \pm 0.11	82.7	49.0	80.0	18.7	6.0	17.3	16.4	5.3	15.3	23 \pm 0.4	37 \pm 3

1: the room with carpet samples

2: the room with virgin gypsum board samples

3: the room with combination of the two materials i.e carpet and virgin gypsum board

Another factor could be that subjects were not familiar with this kind of pollution as they are with painted gypsum board; hence they assessed the air polluted by virgin gypsum board alone as being less acceptable. It could be also assumed that painted gypsum board is a better adsorbent for what is emitted from the carpet but this is hard to prove since the air polluted by virgin gypsum board and the painted gypsum board alone is not perceived equally. Another possibility is that both materials have the same adsorption capacity, but the emission rate and the kind of pollutants emitted from virgin gypsum board are above the adsorption capacity of the carpet. The results also show that the improvement diminishes with time.

3.2.3 Linoleum and painted gypsum board

3.2.3.1 Experiment 5

Thirty-one subjects were recruited to participate in sensory assessments belonging to experiments 5 and 6. The panel consisted of the same subjects throughout all scheduled assessments. Temperature and relative humidity were controlled during both experiments, and they were preset at $T = 22\text{ }^{\circ}\text{C}$ and $\text{RH} = 40\%$ (the measured temperature and relative humidity are shown in Table 3.8). Samples of linoleum and painted gypsum board were ventilated in two different places with high rate supply of outdoor air for 3 days before they were placed inside the rooms for sensory assessments. The results of this experiment are presented in Table 3.8 and Figure 3.8 that shows the mean acceptability assessments of air polluted by linoleum alone and by a combination of linoleum and painted gypsum board for a one-week experiment. It also shows the results for an empty room and a room with painted gypsum board alone after the linoleum was

taken out. The average standard error and the mean standard deviation of the performed assessments were ± 0.07 and ± 0.41 respectively.

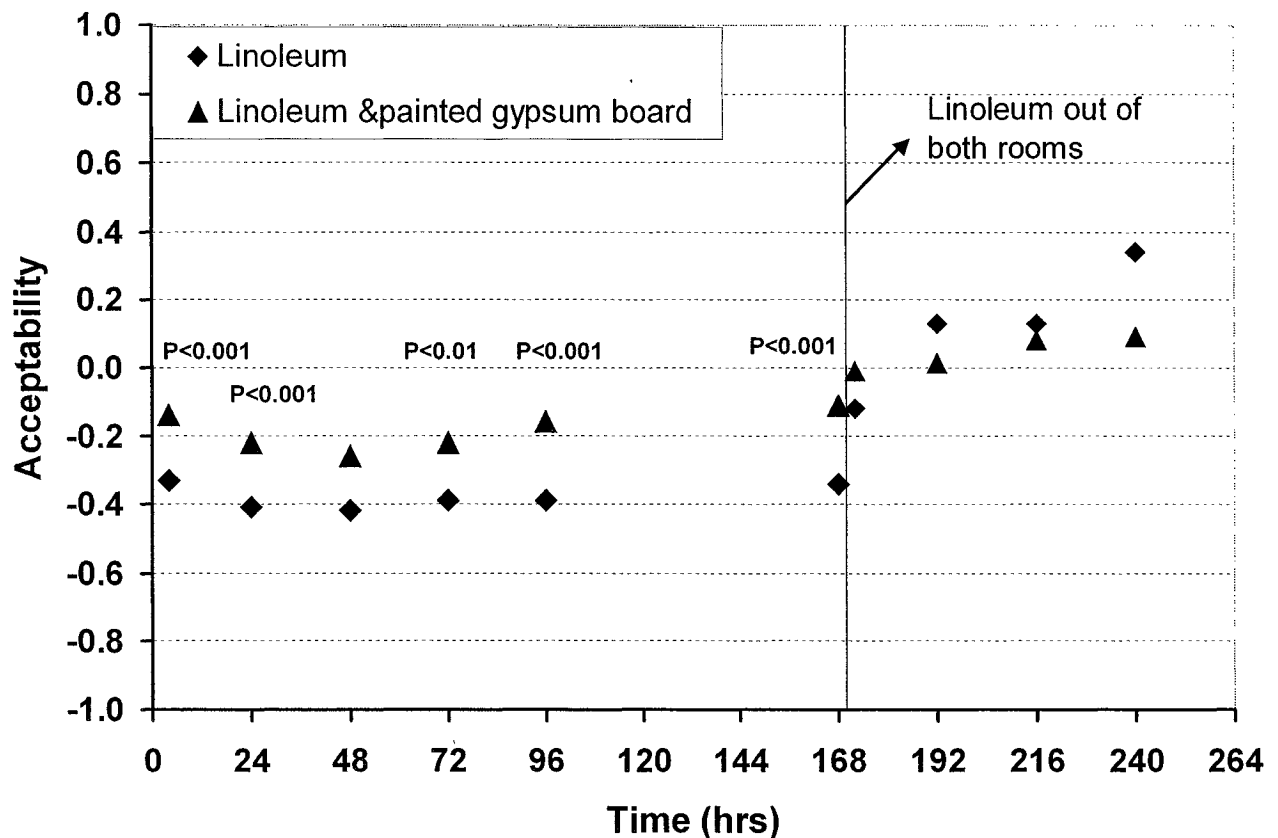


Figure 3.8. Mean assessments of acceptability of air polluted by linoleum and by a combination of linoleum and painted gypsum board. Included are assessments that were made when the linoleum was taken out.

The results of the first part of the experiment (before taking out the linoleum) showed a significant improvement of perceived air quality ($P < 0.001$ for assessments after 4, 24, 72 and 168 hrs, $P < 0.01$ for assessments performed after 72 hrs) when the air was polluted by a combination of two materials (linoleum and painted gypsum board) versus the case of air polluted by linoleum alone. After 72 hrs of placing the materials inside the rooms, and in addition to the official panel, the assessments were performed by 23 guests to the center that day. Based on their assessments, the mean acceptability votes of the room polluted by linoleum alone was $Acc = -0.3$, and $Acc = -0.04$ for the combination

Table 3.8. Perceived air quality and environmental conditions during all assessments of Experiment 5.

Time (hrs)*	Acceptability±Standard error				Percentage dissatisfied			Perceived air quality (decipol)			Pollution load (olf)			Environmental conditions ± Standard deviation	
	Linoleum	Painted gypsum Board (PGB)	Linoleum & painted gypsum board	Linoleum	Linol- eum	(PGB)	Linoleu m& painted gypsum board	Linol- eum	(PGB)	Linoleu m& painted gypsum board	Linol- eum	(PGB)	Linoleu m& painted gypsum board	T °C	RH %
<u>Exper. (5)</u>															
Empty room	0.31±0.08	0.31±0.07	0.38±0.08	14	14	10	0.90	0.9	0.62	0.79	0.79	0.79	0.54	22±0.2	40± 1
Part 1 4	-0.33±0.07	0.06±0.07	-0.14±0.07	82.7	37.8	63.6	18.66	3.69	10.05	16.42	3.25	8.85	22.1±0.1	40± 1	
	-0.41±0.07	0.04±0.07	-0.22±0.08	87.9	40.3	72.7	21.91	4.13	13.63	19.28	3.63	11.99	22.2±0.1	40± 1	
24	-0.42±0.07	0.06±0.07	-0.26±0.07	88.5	37.8	76.7	22.28	3.69	15.49	19.61	3.25	13.63	22.1±0.2	40± 1	
48	-0.39±0.07	0.06±0.07	-0.22±0.07	86.8	37.8	72.7	21.15	3.69	13.63	18.61	3.25	11.99	22 ± 0.2	40± 1	
72	-0.39±0.07	0.1 ±0.07	-0.16±0.07	86.8	33.0	66.0	21.15	2.94	10.91	18.61	2.59	9.60	22.1±0.1	40± 1	
96	-0.34±0.07	0.04±0.08	-0.11±0.07	83.4	40.3	59.9	19.10	4.13	8.82	16.81	3.63	7.76	22.3±0.2	40± 1	
<u>Part 2</u> Linoleum out	Empty		Painted gypsum board	Empty		Painted gypsum board	Empty		Painted gypsum board	Empty		Painted gypsum board			
172	-0.12±0.07		-0.01±0.08	61.1		47.0	9.2		5.4	8.1		4.8	22.4±0.2	40± 1	
192	0.13±0.09		0.014±0.07	29.6		44.0	2.5		4.8	2.2		4.2	22.3±0.2	40± 1	
216	0.13±0.09		0.08±0.07	29.6		35.4	2.5		3.3	2.2		2.9	22.3±0.2	40± 1	
240	0.34±0.08		0.09±0.07	12.2		34.2	0.8		3.1	0.7		2.7	22.3±0.3	40± 1	

of linoleum and painted gypsum board. The statistical analysis of their acceptability assessments resulted in the same level of significance obtained by the official panel ($P < 0.01$).

The results of acceptability assessments performed 4 hrs after linoleum was taken out of the room showed a significant improvement of the perceived air quality in both rooms but it took three days for the empty room and two days for the room with painted gypsum board to get rid of the impact of having linoleum earlier.

3.2.4 Linoleum and Semia

3.2.4.1 Experiment 6

In this experiment linoleum and Semia (absorbing sheets consisting of activated charcoal) were tested individually and as a combination for one week, after which linoleum was taken out of the rooms and the sensory panel proceeded in assessing the air quality in the three rooms; the two that had linoleum before and the one that continued to have the same Semia samples. The three rooms had the same air exchange rate ($ACH = 0.8 \pm 0.02 \text{ h}^{-1}$), and the same environmental conditions of the preset temperature and relative humidity ($T = 22^\circ \text{ C}$, $RH = 40 \%$). The average measured temperature in the three rooms \pm standard deviation are shown in Table 3.9. Temperature and relative humidity were measured each day before the start of sensory assessments. The sensory panel assessed the acceptability of the air in the three rooms, after 4, 24, 48, 72, 96, 168 hrs after the materials were introduced to the rooms and then 4, 24, 48 and 72 hrs after the linoleum was taken out of the room, with an average standard error of ± 0.08 (mean standard deviation of ± 0.45). The results of sensory assessments, also presented in Table

3.9 and in Figure 3.9, show that when Semia was tested alone the acceptability of the air was as good as an empty room. In addition to that a big improvement on the perceived air quality was observed when linoleum was placed together with Semia in the same room in comparison to when linoleum was tested alone. The assessments of acceptability performed 4 hrs after placing the materials inside the rooms showed that the air quality in the room that contained linoleum with Semia was perceived as good as the room having only Semia (or an empty room). 24 hrs later the acceptability dropped to be almost the same for the rest of the assessments (further deterioration was observed for the assessments performed after one week). The improvement was statistically significant for all performed assessments ($P < 0.0001$) indicating the high sorption ability of Semia.

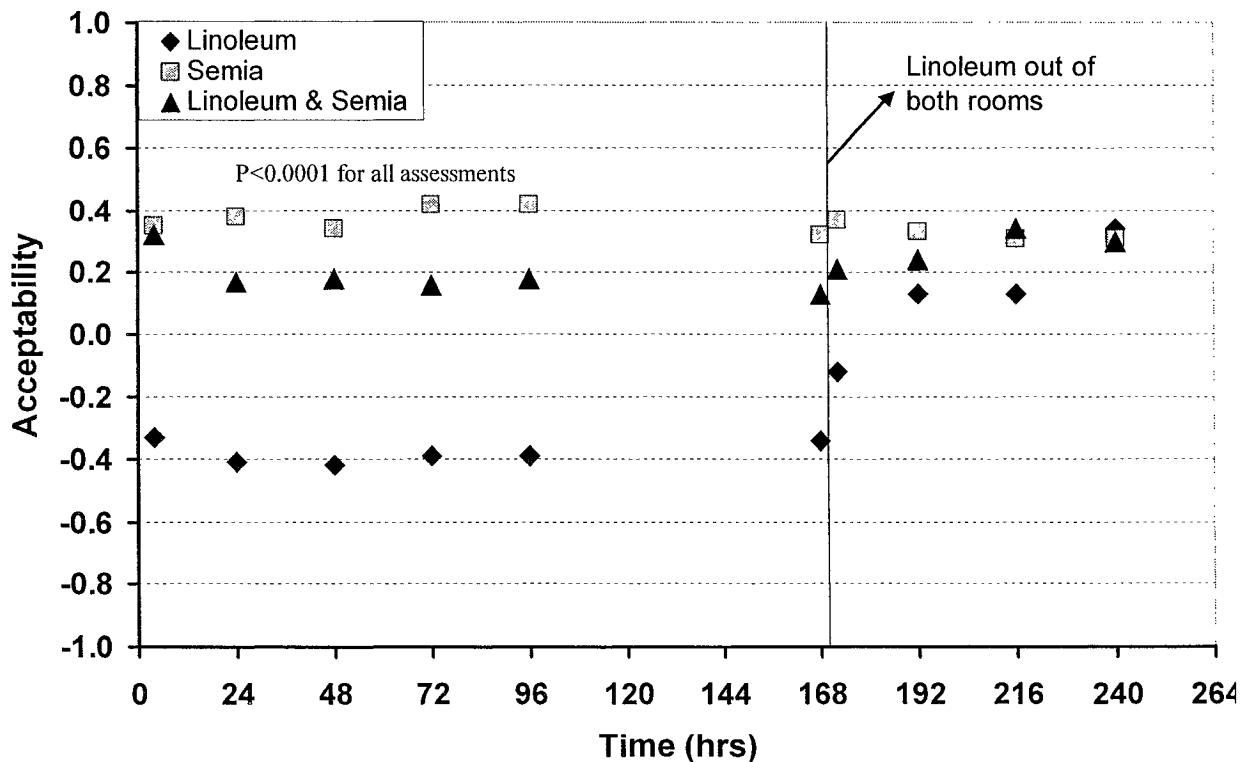


Figure 3.9. Mean assessments of acceptability of air polluted by linoleum, Semia and by a combination of linoleum and Semia. Included are assessments that were made after the linoleum was taken out.

Table 3.9. Perceived air quality and environmental conditions during all of the assessments performed during Experiment 6.

Time (hrs)*	Acceptability±Standard error			Percentage dissatisfied			Perceived air quality (decipol)			Pollution load (olf)			Environmental conditions ± Standard deviation	
	Linoleum	Semia	Linoleum+ Semia	Linol- eum	Semia	Linoleum +Semia	Linoleum	Semia	Linoleum +Semia	Linolem	Semia	Linoleum +Semia	T °C	RH %
<u>Exper. (6)</u> Empty rooms Part 1														
4	0.31±0.08	0.38±0.07	0.35±0.07	14	10	12	0.90	0.62	0.72	0.79	0.54	0.64	22±0.2	40± 1
24	-0.33±0.07	0.35±0.08	0.32±0.08	82.7	11.6	13.4	18.66	0.72	0.85	16.42	0.64	0.75	22.1±0.1	40± 1
48	-0.41±0.07	0.38±0.08	0.17±0.09	87.9	10.1	25.4	21.91	0.62	1.97	19.28	0.54	1.73	22.2±0.1	40± 1
72	-0.42±0.07	0.34±0.09	0.18±0.08	88.5	12.2	24.4	22.28	0.76	1.86	19.61	0.67	1.64	22.1±0.2	40± 1
96	-0.39±0.07	0.42±0.08	0.16±0.08	86.8	8.3	26.4	21.15	0.50	2.09	18.61	0.44	1.84	22± 0.2	40± 1
168	-0.39±0.07	0.42±0.08	0.18±0.08	86.8	8.3	24.4	21.15	0.50	1.86	18.61	0.44	1.64	22.1±0.1	40± 1
	-0.34±0.07	0.32±0.09	0.13±0.09	83.4	13.4	29.6	19.10	0.85	2.48	16.81	0.75	2.18	22.3±0.2	40± 1
Part 2 Linoleum out														
172	Empty	0.37±0.1	0.21±0.1	Empty	10.6	21.6	9.2	0.7	1.6	8.1	0.6	1.4	22.4±0.2	40± 1
192	-0.12±0.07	0.33±0.09	0.24±0.09	61.1	12.8	19.0	2.5	0.8	1.3	2.2	0.7	1.2	22.3±0.2	40± 1
216	0.13±0.09	0.31±0.08	0.34±0.08	29.6	14.0	12.2	2.5	0.9	0.8	2.2	0.8	0.7	22.3±0.2	40± 1
240	0.13±0.09	0.31±0.09	0.3±0.08	29.6	14.0	14.6	0.8	0.9	0.9	0.7	0.8	0.8	22.3±0.3	40± 1

By taking the linoleum out of the rooms the acceptability of the air started to improve in both rooms (the big improvement was 4 hrs after removing the linoleum) but it took two and three days for the air quality to be perceived as good as a room with Semia alone and as an empty room. The air of the room that had only Semia from the beginning continued to be perceived as being almost the same for all assessment sessions (See Figure 3.9)

3.3 Discussion

These experiments (outlined in Table 3.1) have demonstrated that air polluted by two different building materials placed in the same room is perceived to be better than air in a room polluted by the more polluting of the two materials; sometimes air polluted by two different materials is even better than air in a room polluted by the less polluting material. Assessments performed after 4 hrs in Experiment 1 and all assessments in Experiment 7 show that the air polluted by carpet and painted gypsum board was perceived to be better than the air polluted by carpet alone or painted gypsum board alone.

Based on the results of Experiments 1, 2, 3, 4 and 7, the average percentage dissatisfied caused by air polluted by carpet decreased by approximately 25% when carpet was placed together with painted gypsum board, and by 10% when carpet was placed together with virgin gypsum board. Results from Experiments 5 and 6 show that the percentage dissatisfied due to air polluted by linoleum dropped by 18% for a combination of linoleum and painted gypsum board and 65% when linoleum and Semia were placed together in the same room. From Experiment 7 it was possible to investigate the sink effect associated with the room surfaces. As mentioned earlier, air polluted by carpet (Room 1) and painted gypsum board (Room 3) was mixed in Room 2, where the only

sinks were the room surfaces. The improvement in perceived air quality in this room in comparison to the air polluted by the individual material is believed to be mainly due to sorption on the room surfaces. The results show that the percentage dissatisfied with the air in the mixing room was, on average, 14% less than the percentage dissatisfied with the air in the room with carpet alone.

Whether the improvements were statistically significant or not, taken together the results from Experiments 1 through 7 are consistent despite the different kinds of building materials used in the experiments, the different panels that performed the sensory assessments and the different environmental conditions for the different experiments. The results indicate that the tested building materials interact with each other and with the room surfaces by sorption/desorption phenomena. The pollutants emitted from one material are adsorbed on the surface of the other material and on the room surfaces, reducing the concentration of pollutants and affecting the perceived air quality. Another indication of the occurrence of sorption is apparent in the results of Experiments 3, 5 and 6 during the desorption stage. In these experiments, when the strong pollution source (carpet or linoleum) was taken out of the room, more than three days of ventilation were required before the room air was perceived to be free of the emissions from the polluting material. This indicates that sorption took place when the material was present, and when the polluting material was removed, the concentration of pollutants in the air dropped and the pollutants that had been adsorbed on the surfaces of the room or the gypsum board desorbed into the room air, prolonging the presence of certain pollutants (from carpet or linoleum) in the room air even after the source had been removed.

The results of the aforementioned experiments indicate that sorption affects the perceived

air quality significantly. In the next chapter the impact of sorption phenomena will be quantified. Adsorption/desorption coefficients will be calculated based on results from the experiments detailed in the present chapter. These calculations will permit comparisons among the different materials when exposed to different pollution sources.

CHAPTER 4

DETERMINATION OF SORPTION PARAMETERS

Data obtained from the experiments cited in the previous chapter were analyzed assuming a Langmuir type of adsorption and using the sink model proposed by Tichenor et al. (1991). The aim was to calculate adsorption desorption coefficients to characterize the sink effect of the room surfaces and painted gypsum boards when the source of pollution was either carpet or linoleum.

4.1 Background

The linear Langmuir model is the most widely used model to predict sorption, due to its simplicity of use and acceptable accuracy when applied under appropriate conditions (well mixed room with low concentration of pollutants, smooth surfaces for materials that act as sink for indoor pollutants). Tichenor et al. (1991) used the Langmuir model, to examine the impact of sorption on indoor environments. They studied sorption/desorption of two chemicals with five common building materials. They concluded that the model is appropriate to study sorption for flat smooth surfaces like wallboard but less appropriate for complex surfaces like carpet where diffusion into the materials should be taken into account. Since then, many researchers have used the Langmuir model to study the interaction of indoor pollutants and materials surfaces (Jorgensen et al. 1991, Jorgensen and Bjorseth 1999, An et al. 1999, Won et al. 2001, Zhang et al 2001). These researchers have found that the linear sink model is appropriate to describe the sink effect for a range of chemicals concentrations found indoors.

Herein, the linear Langmuir model will be used to predict sorptive interactions between indoor pollutants emitted from building materials (carpet or linoleum) and indoor materials surfaces (painted gypsum board and the room surfaces). In this chapter, carpet and linoleum will be considered as pollution sources while gypsum board and the room surfaces will be treated as sinks. These assumptions were made to simplify the calculations, and are based on the fact that carpet and linoleum were much stronger pollution sources than the painted gypsum board or the room surfaces used in the experiments detailed in Chapter 3. Data from sensory measurements in the rooms that had one building materials, in room with a combination of two materials, and in the mixing room (where the air was polluted by building materials located outside the room), will be used to estimate sorption parameters for the room surfaces and for painted gypsum board.

4.1.1 Principle of Langmuir model applied in this study

Sorption in the test rooms used in the experiments presented in Chapter 3 can be described using Figure 4.1 where the outdoor airflow rate to the room is Q and the outdoor air pollutants concentration is C_o . $G(t)$ is the emission rate of the pollution source. The exhaust air has a concentration equal to the room concentration $C(t)$. The mass of indoor pollutants adsorbed per unit area of the room surfaces is $M_{\text{room}}(t)$. $k_{\text{aroom}}C(t)$ and $k_{\text{droom}} M_{\text{room}}(t)$ are the adsorption rate to the room surfaces and the desorption rate from the room surfaces to the room air. $M_1(t)$ is the mass of indoor pollutants adsorbed per unit area of test material that act as a sink. The adsorption rate from the room air to the surface of test sample is $k_{a1} C(t)$ and the desorption rate from the

surface of building materials sample to the bulk air is $k_{d1} M_1(t)$.

Sorption parameters, represented by the mass per unit area of the sink (M_e) the equilibrium constant (K_e) (also referred to as the material/air equilibrium partition coefficient), the desorption rate constant k_d and the adsorption rate constant k_a could be determined using the time concentration data during adsorption stage only, desorption stage only or the whole adsorption /desorption period.

We will begin with a summary of the calculations that apply during the desorption stage of the experiments.

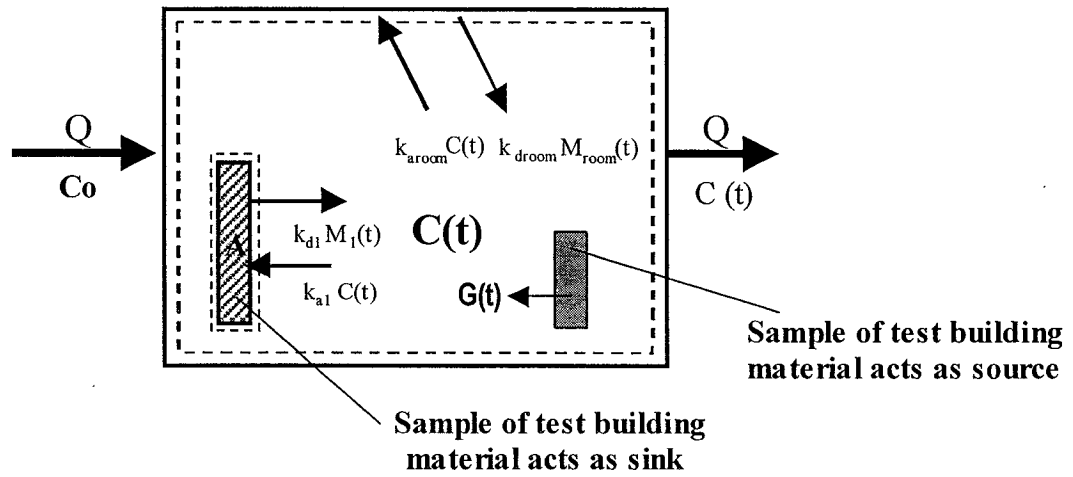


Figure 4.1 Schema of sorption in the test room

The first step is to calculate the mass in the sink that is assumed to be at equilibrium with room air at (t_s) just before the pollution source was taken out of the room. The total mass of pollutant measured from (t_s) until the end of the experiment is equal to the mass in the chamber air at (t_s) plus the mass of pollutants emitted from the sink (M_e). The total mass of pollutants can be obtained from the area under the desorption curve (A_c) multiplied by the air exchange rate (N) and the chamber volume (V). This desorption curve represents

the relationship between the perceived concentration and the time (see, for example, Figure 4.2).

The area under the curve is calculated using the trapezoid rule (see appendix B):

$$A_c = \sum [(C_i + C_{i+1})(t_{i+1} - t_i)/2] \quad \dots\dots\dots (4.1)$$

The mass of the pollutants in the room air is the product of the concentration at equilibrium (C_e) and the chamber volume (V).

And the equilibrium mass in the sink per unit area (decipol m^3/m^2) is:

$$M_e = (A_c N V - C_e V) / A \quad \dots\dots\dots (4.2)$$

The strength of the sink expressed by the equilibrium coefficient K_e , could be determined assuming a Langmuir type of adsorption. At equilibrium the Langmuir isotherm can be described as:

$$k_a C_e (1 - \theta) = k_d' \theta \quad \dots\dots\dots (4.3)$$

where :

k_a : adsorption rate constant (m/h)

C_e : equilibrium concentration (decipol)

k_d' : desorption constant (mg/ m^2 .h)

θ : proportion of available adsorption sites occupied

For low indoors pollutants concentrations, as was the case in these studies, it can be assumed that the sites occupied are a very small fraction of the available sites ($\theta \ll 1$) and

the previous equation can be reduced to the linear equation:

$$k_a C_e = k_d' \theta \quad \dots\dots\dots (4.4)$$

The mass in the sink per unit area at equilibrium M_e is proportional to the available

adsorption sites occupied and therefore:

$$k_a C_e = k_d M_e \dots\dots\dots(4.5)$$

k_d : desorption rate constant (h^{-1})

And the equilibrium constant K_e is equal to k_a/k_d or M_e/C_e

4.1.1.1 Determination of k_a and k_d :

The sink model proposed by Tichenor et al (1991) assumes that the air in the room is perfectly mixed and that at equilibrium the sorption rate $k_a C_e$ is equal to the desorption rate $k_d M_e$ (Langmuir adsorption process). Based on these assumptions the following differential equations were developed:

$$dC_t/dt = NC_{in} - NC_t - k_a C_t L + k_d M L \dots\dots\dots(4.6)$$

$$dM/dt = k_a C_t - k_d M \dots\dots\dots(4.7)$$

where:

C_t : the concentration in the room (mg/m^3 or decipol for the perceived concentration)

C_{in} : concentration of pollutant in the inlet air (mg/m^3 or decipol)

k_a : adsorption rate constant (m/h)

k_d : desorption rate constant (h^{-1})

L : loading factor = sink area/volume of the room (m^{-1})

M : mass per unit area of the sink (mg/m^2 or decipol $\cdot m^3/m^2$)

The previous mass balance equations were solved for the desorption phase considering the following initial conditions: $t=0$, $C(0)=C_e$ and $M(0)=M_e=C_e(k_a/k_d)$ (Tichenor et al.1991):

$$C(t) = C_e ((N-r_2) e^{-r_1 t} - (N-r_1) e^{-r_2 t}) / (r_1 - r_2) \dots\dots\dots(4.8)$$

$$M(t) = k_a C_e (r_1 e^{-r_2 t} - r_2 e^{-r_1 t}) / k_d (r_1 - r_2) \dots\dots\dots(4.9)$$

Where:

$$r_{1,2} = [(N + k_a L + k_d) \pm ((N + k_a L + k_d)^2 - 4 N k_d)^{1/2}] / 2 \dots\dots(4.10)$$

Values for k_a and k_d could be obtained by fitting Equation (4.8), where C_e is a known experimental value, to the room concentration versus time data from (t_s) to the end of the test using a nonlinear regression curve fit routine.

The aforementioned procedure was used to find sorption parameters for the room surfaces.

4.2 Sorption parameters for the room surfaces

4.2.1 Calculations based on data from the desorption stage (Tichenor model, 1991)

Using the procedure just described, the sensory assessments performed after the equilibrium was reached and the pollution source was taken out of the room were used to calculate the mass in the sink (M_e), the equilibrium constant (K_e), the desorption rate constant (k_d) and the adsorption rate constant (k_a).

4.2.1.1 Sorption parameters for the room surfaces when carpet was the pollution source during sorption period

The result of sensory assessments for Experiment 3, Chapter 3, during desorption stage are shown in Table 4.1. Assessments were performed just before the carpet was taken out of the room and then 4, 24 and 48 hrs after it has been taken out.

Table 4.1 Sensory assessments for an empty room, after the carpet samples were taken out of the room.

Time (after the materials were taken out of the room) (hrs)	Acceptability	Perceived air quality (decipol)
0	-0.33	18.7
4	0.13	2.5
24	0.15	2.2
48	0.28	1.1

The change in perceived air quality with time, during the desorption stage, is presented in Figure 4.2. The figure was used to calculate A_c (area under the curve) using the trapezoid rule (see appendix B for detailed calculations):

$$A_c = 101.08 \text{ decipol} \cdot \text{h}$$

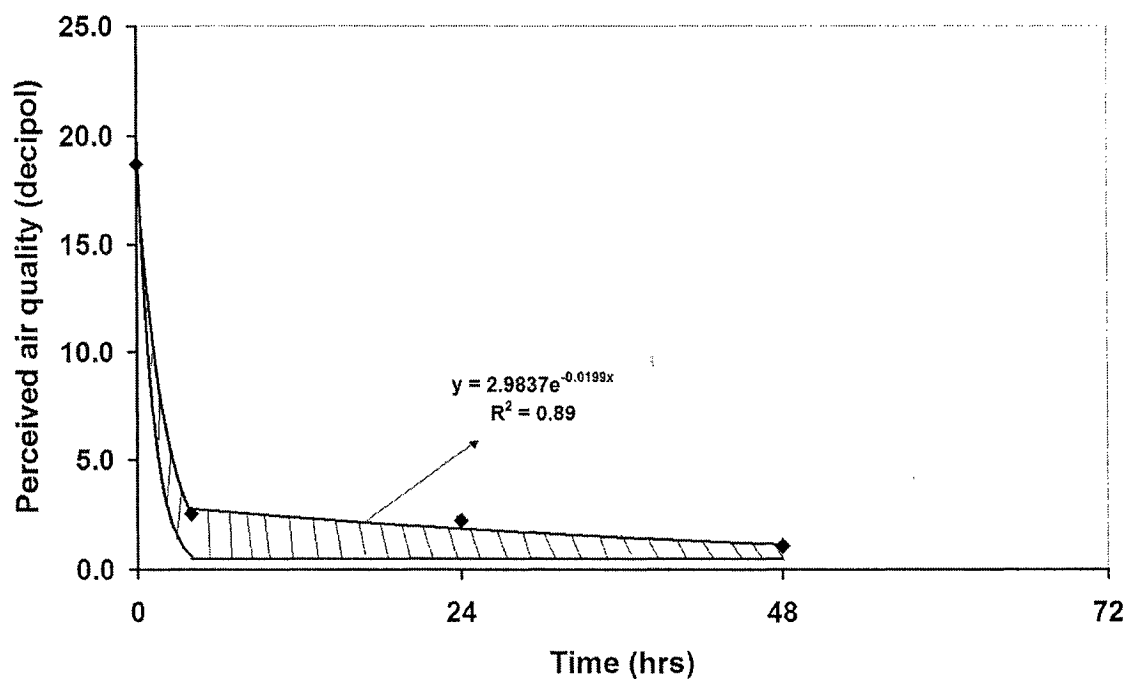


Figure 4.2 Perceived air quality for the empty room, after the carpet was taken out. Desorption from the room surfaces is represented by hatched area.

The mass per unit area of the sink: $M_c = (A_c Q - C_e V) / A$

Where $Q=N*V$ in Equation 4.2

$$M_e = ((101.1*32) - 18.7*40) / 90 = 27.63 \text{ decipol m}^3/\text{m}^2$$

$$K_e = M_e/C_e = 27.63/ 18.7 = 1.48 \text{ m}$$

$$k_a = K_e * k_d = 1.48 k_d$$

$$r_1 = [(N + 1.48k_d L + k_d) + ((N + 1.48 k_d *L)^2 - 4 N k_d))^{1/2}] /2$$

$$r_2 = [(N + 1.48k_d L + k_d) - ((N + 1.48 k_d *L)^2 - 4 N k_d))^{1/2}] /2$$

N : the air exchange rate in the room $=0.8 \text{ h}^{-1}$

L : loading factor and it is equal to (room surface area/volume of the room) =

$$90/40 = 2.25 \text{ m}^{-1}$$

For each value assumed for k_d , r_1 and r_2 were calculated and used to find $C(t)'$:

$$C(t)' = C_e ((N-r_2) e^{-r_1 t} - (N-r_1) e^{-r_2 t}) / (r_1-r_2) \dots\dots\dots(4.11)$$

Where:

C_e is the perceived concentration just before the source of pollution was taken out of the room (in this experiment $C_e = 18.7$ decipol)

The least square method was applied to determine the value of k_d (that gives the minimum sum of $(C_t - C_t')^2$

For this experiment:

$$r_1 = 0.92, \quad r_2 = 0.03$$

$$\text{Sum of errors} = 1.21, \quad k_d = 0.035 \text{ h}^{-1} \quad \text{and} \quad k_a = 1.48 * 0.035 = 0.052 \text{ m/h}$$

4.2.1.2 Sorption parameters for the room surfaces when linoleum was the pollution source during the sorption period

The same procedure detailed above was applied on the sensory data obtained from

Experiment 5, Chapter 3. Again, sensory assessments were performed before taking out the linoleum and then 4, 24, 48, and 72 hours after taking linoleum samples out of the room. The results are presented in Table 4.2 and Figure 4.3. The hatched area represents desorption.

Table 4.2 Sensory assessments for the empty room after the linoleum samples were taken out of the room.

Time (after the materials were taken out of the room) (hrs)	Acceptability	Perceived air quality (decipol)
0	-0.34	19.1
4	-0.12	9.2
24	0.13	2.5
48	0.13	2.5
72	0.34	0.8

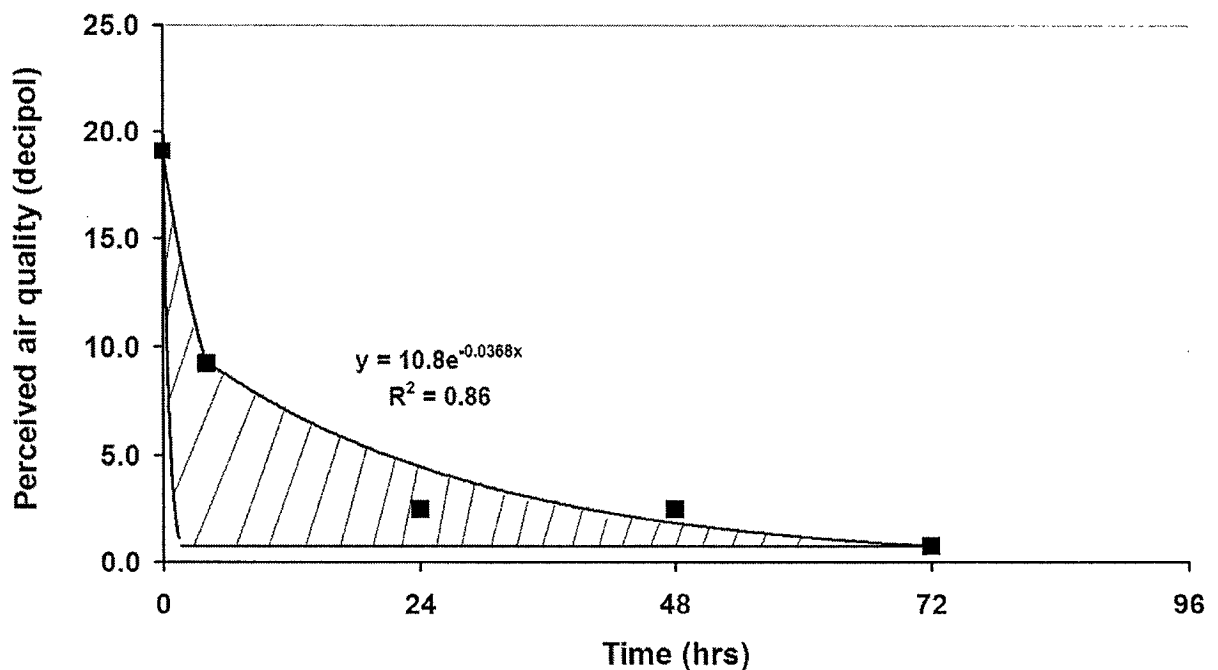


Figure 4.3. Perceived air quality for the empty room, after the linoleum was taken out. Desorption from the room surfaces is represented by hatched area.

Again the area under the curve was calculated using trapezoid rule and below are the

Calculation results:

$$A_c = 229.4 \text{ decipol} \cdot \text{h}, M_e = 73.09 \text{ decipol m}^3/\text{m}^2, K_e = M_e/C_e = 3.8 \text{ m}$$

$$r_1 = 1.81, r_2 = 0.05 \text{ and } k_d = 0.11 \text{ h}^{-1}$$

$$k_a = K_e \cdot k_d = 3.8 \cdot 0.11 = 0.42 \text{ m/h}, \text{ Sum of errors} = 3.1$$

Adsorption and desorption rate constants when linoleum was the pollution source are:

$$k_a = 0.42 \text{ m/h and } k_d = 0.11 \text{ h}^{-1}$$

A summary of the sorption parameters for the room surfaces when the source of pollution was either carpet or linoleum is presented in Table 4.3

Table 4.3 Sorption parameters for the room surfaces when either carpet or linoleum was the pollution source.

Pollution source	k_a m/h	k_d h^{-1}	K_e m	M_e decipol m^3/m^2
Carpet	0.05	0.04	1.48	28
Linoleum	0.42	0.11	3.8	73

4.2.2 Calculation of adsorption rate constant for the test room surfaces based on data from the adsorption stage

As mentioned before, sorption parameters could be estimated from the adsorption stage data, desorption stage data or data from both stages. In the experiments shown in Chapter 3, it was impossible to get a clear sorption curve (exponential curve)

demonstrating the increase in concentration in the room air until the equilibrium is reached. The reason is mostly due to the presence of the pollution sources (linoleum or carpet) and the sink (room surfaces, painted gypsum board) in the same place. Although it was assumed that linoleum and carpet will be considered as emission sources and the room surfaces and painted gypsum boards as sink but in reality all surfaces in one place act as pollution sources and as sinks at the same time. As mentioned earlier, the assumption was made, for simplification and based on fact, that emissions from carpet and linoleum were much more important than those from room surfaces or painted gypsum board. In addition the area, an important factor in sorption, was bigger for room surfaces and painted gypsum board ($A_{\text{room}} = 90 \text{ m}^2$, $A_{\text{PGB}} = 23 \text{ m}^2$) than the ones for linoleum or carpet ($A_{\text{carpet}} = A_{\text{linoleum}} = 14 \text{ m}^2$). The calculations shown below are based on the assumption that for the first assessments performed after the materials were placed inside the room the impact of adsorption is much higher than the impact of desorption and at this point, desorption could be neglected. In Experiments 3 and 7 detailed in Chapter 3, carpet and painted gypsum board were tested individually, in combination, and when air polluted by carpet and painted gypsum board was combined in a mixing room. By applying the mass balance equation on the first sensory assessments data performed after the pollution source was introduced to the rooms, and by assuming that the change in concentration in a very small fraction of time is small and could be neglected, the following equations could be derived:

For the room that contained only carpet:

$$C_{\text{carpet}} = G_{\text{carpet}} / 0.1 (Q + k_{a \text{ room}} * A_{\text{room}}) \dots\dots\dots(4.12)$$

For the room that contained only painted gypsum board

$$C_{PGB} = G_{PGB} / 0.1 (Q + k_{a \text{ room}} * A_{\text{room}}) \dots\dots\dots(4.13)$$

Where:

C_{carpet} or C_{PGB} : perceived air quality in the room that had samples of carpet or painted gypsum board (decipol)

G_{carpet} : sensory emission or sensory pollution load caused by carpet (olf)

G_{PGB} : sensory pollution load caused by painted gypsum board (olf)

Q : outdoor air supply rate to the room (l/s) or (m^3/h)

$k_{a \text{ room}} * A_{\text{room}}$: surface removal (m^3/h)

A_{room} : area of the room surfaces (m^2)

$k_{a \text{ room}}$: deposition velocity or adsorption rate coefficient for the room surfaces (m/h)

For the mixing room that takes air from the two adjacent rooms where carpet and painted gypsum board were placed and ventilated, see Figure 4.4. The concentration in that room could be expressed by the following equation :

$$C_{\text{mixing room}} = (G_{\text{carpet}} + G_{\text{painted gypsum board}}) / 0.1 * (Q + k_{a \text{ room}} * A_{\text{room}}) \dots\dots\dots (4.14)$$

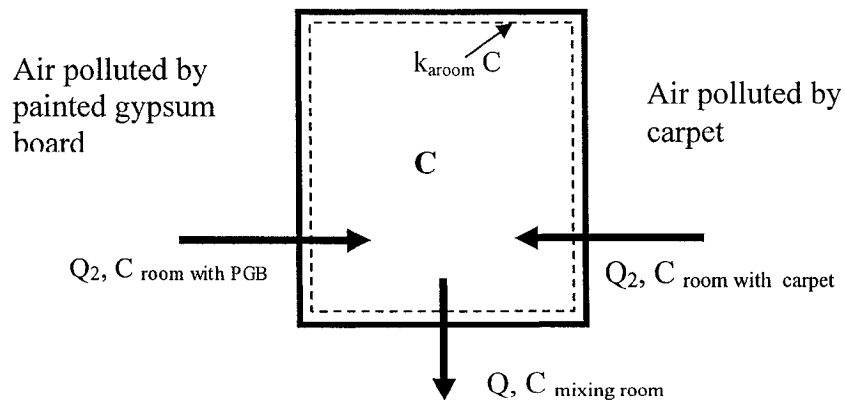


Figure 4.4 Mass balance for the mixing room

Where:

$C_{\text{mixing room}}$: perceived air quality in the mixing room (decipol)

$G_{\text{(carpet)}}$: sensory pollution load caused by carpet and transmitted from the room that contains carpet to the mixing room (olf)

$G_{\text{(PGB)}}$: sensory pollution load caused by painted gypsum board in the adjacent room and transmitted to the mixing room (olf)

Q : air supply to the room (from the two adjacent rooms that contain carpet or painted gypsum board) = $2 Q_2$ (l/s) or (m^3/h)

A_{room} : area of the room surfaces (m^2)

$k_{a \text{ room}}$: adsorption rate coefficient for the pollutants from carpet and painted gypsum board sorbed on the room surfaces (m/h)

For the room where samples of carpet and painted gypsum board were placed together the change in the room concentration is due to the impact of ventilation, the impact of sorption on the room surfaces and the impact of sorption on painted gypsum boards. The carpet also adsorbs some of the pollutants; however, since it is the source of these pollutants the net sorption to carpet is expected to be small in comparison to the sorption on room surfaces and painted gypsum board and for simplification it was neglected. Hence, carpet was considered as the pollution source while painted gypsum board was considered as a sink. Based on that and from the mass balance equation applied during the early assessments, when desorption was small, the concentration in the room with the combination of carpet and painted gypsum board could be estimated from the following equation:

$$C_m = (G_{\text{carpet}} + G_{\text{PGB}}) / 0.1 * (Q + k_{a \text{ room}} * A_{\text{room}} + k_{a \text{ gypsum board}} * A_{\text{gypsum board}}) \dots \dots \dots (4.15)$$

Where:

C_m : perceived air quality measured in the room where the two materials were placed

together (decipol)

G_{carpet} : pollution load caused by the carpet when tested individually (olf)

$$G_{\text{carpet}} = 0.1 * C_{\text{carpet}} * (Q + k_{a \text{ room}} A_{\text{room}})$$

G_{PGB} : pollution load caused by painted gypsum board tested individually (olf)

$$G_{\text{PGB}} = 0.1 * C_{\text{painted gypsum board}} * (Q + k_{a \text{ room}} A_{\text{room}})$$

Q : outdoor air supply to the room (l/s) or (m³/h)

$k_{a \text{ room}}$: adsorption rate coefficient for the room surfaces (m/h)

A_{room} : area of the room surfaces (m²)

$k_{a \text{ painted gypsum board}}$: adsorption rate coefficient for the painted gypsum board (m/h)

$A_{\text{gypsum board}}$: area of gypsum board samples used in the experiment (m²)

4.2.2.1 Calculation of adsorption rate constant for the room surfaces $k_{a \text{ room}}$ when the pollution source was samples of the carpet

Equation (4.14) was applied to data from Experiment 7, Chapter 3 to find the adsorption rate constant for the room surfaces ($k_{a \text{ room}}$). Sensory assessments used in the calculation were the one performed 8 hrs after carpet and painted gypsum boards were placed in the two adjacent rooms. See table 4.4.

The calculation resulted in $k_{a \text{ room}} = 0.05$ m/h; this value is quite similar to the value calculated previously ($k_{a \text{ room}} = 0.06$) during the desorption stage. Considering that the data used to obtain these values for k_a were from two different experiments performed using different subjects, the agreement is remarkably good. It should be noted that An et al. (1999) and Zhang et al (2001) reported that k_a estimated from different periods (adsorption period only, desorption period only or periods when both processes were important) were not always consistent for the VOCs that they evaluated.

Table 4.4 Calculation of adsorption rate constant for the room surfaces ($k_{a \text{ room}}$) using sensory assessments from Experiment 7, Chapter 3

Time (hrs)	C (mixing room) (decipol) (1)	$C_{(PGB)}$ (painted gypsum board) (decipol) (2)	$C_{(C)}$ (carpet) (decipol) (3)	$C_{(PGB)+}$ $C_{(C)}$ (decipol) (4)	Q_2 (l/s) (5)	$(4)^*(5)$ (6)	$(6)/(1)$ (l/s) (7)	$(7)^*3.6$ (m ³ /h) (8)	Q (m ³ /h)	A (m ²) (9)	$k_{a \text{ (room)}}$ (m/h)
8	6.31	6.0	8.43	14.43	4.4	63.49	10.06	36.22	32	90	0.05

4.3 Sorption parameters for painted gypsum board

4.3.1 Adsorption rate constant for painted gypsum board k_{aPGB} calculated from adsorption stage data

4.3.1.1 When carpet was the source of pollution

Data from Experiment 7, Table 3.6, was used together with Equations (4.12) (4.13) and (4.15) to find k_{aPGB} . Sensory assessments used in the calculation were the ones performed 8 hrs after the materials were placed inside the rooms. The results are shown in Table 4.5. The adsorption rate constant for carpet emissions to painted gypsum board was found to be equal to $k_{aPGB} = 2.48$ m/h. Calculations were also performed using data from Experiment 3, Table 3.5 that was performed with a different sensory panel but in the same rooms as the other experiments and using the same test materials; k_{aPGB} was found to be equal to 3.06 m/h. Results are shown in Table 4.6.

4.3.1.2 When Linoleum was the source of pollution

After replacing G_{carpet} by $G_{linoleum}$ in Equations (4.12) and (4.15), they were used together with Equation (4.13) to estimate k_{aPGB} when linoleum was the source of pollution. The data used in the calculation were the results of the early sensory assessments performed after the materials were placed inside the rooms for Experiment 5, Table 3.8. The calculated results are shown in Table 4.7 and the adsorption rate constant for painted gypsum board when linoleum is the pollution source was found to be $k_{aPGB} = 3.7$ m/h

Table 4.5. Calculation of adsorption rate constant for painted gypsum board (k_a PGB) using sensory assessments from Experiment 7 Chapter 3 when carpet was used as pollution source

Time (hrs)	$C_{(c)}$ (carpet) (decipol) (1)	$C_{(PGB)}$ (painted gypsum board) (decipol) (2)	$C_p = (1)+(2)$ (3)	$Q^* = Q + k_{a,room}^{(1)} * A_{room}$ (4)	Q (m^3/h) (5)	C_m (decipol) (6)	C_m/C_p (7)	(4)/(7) (8)	(8)-(4) (9)	A (m^2) (10)	k_a painted gypsum board (m/h) (11)
8	8.43	6.0	14.43	37.4	32	5.69	0.39	93.6	57.1	23	2.48

Table 4.6. Calculation of adsorption rate constant for painted gypsum board (k_a PGB) using sensory assessments from Experiment 3 Chapter 3 when carpet was used as pollution source

Time (hrs)	$C_{(c)}$ (carpet) (decipol) (1)	$C_{(PGB)}$ (painted gypsum board) (decipol) (2)	$C_p = (1)+(2)$ (3)	$Q^* = Q + k_{a,room}^{(1)} * A_{room}$ (4)	Q (m^3/h) (5)	C_m (decipol) (6)	C_m/C_p (7)	(4)/(7) (8)	(8)-(4) (9)	A (m^2) (10)	k_a painted gypsum board (m/h) (11)
4	14.6	3.90	18.46	37.4	32	6.3	0.34	110	72.6	23	3.06

$k_a^{(1)} = 0.06 \text{ m/h}$ (adsorption rate constant for the room surfaces when carpet was used as pollution source; see Table 4.3)

Table 4.7. Calculation of adsorption rate constant for painted gypsum board ($k_{a \text{ PGB}}$) using sensory assessments from Experiment 5, Chapter 3 when linoleum was used as pollution source

Time (hrs)	$C_{(L)}$ (linoleum) (decipol) (1)	$C_{(PGB)}$ (painted gypsum board) (decipol) (2)	$C_p =$ (1)+(2) (3)	$Q^* = Q + k_{\text{room}}^{(2)} \cdot A_{\text{room}}$ (4)	Q m^3/h (5)	C_m (decipol) (6)	C_m/C_p (7)	$(4)/(7)$ (8)	$(8)-(4)$	A (m^2)	k_a painted gypsum board (m/h)
4	18.7	3.7	22.4	69.8	32	10.1	0.45	155.22	85	23	3.7

$k_{\text{room}}^{(2)} = 0.42 \text{ m}/\text{h}$ (adsorption rate constant for room surfaces when linoleum was the pollution source; see Table 4.3)

4.3.2 Sorption parameters for painted gypsum boards, estimation based on desorption stage data:

Sensory assessments performed in the room with painted gypsum boards just before and after the pollution source (carpet or linoleum) was taken out, i.e. during the desorption stage, were used to determine sorption parameters for the room with painted gypsum board. Tichenor model assumes that there is no sink effect from the room surfaces or the effect is very small. To account for mass adsorbed and desorbed from the actual test room surfaces in addition to the test material surfaces that act as a sink, two more terms should be added to Tichenor mass balance. Thus Equation 4.6 becomes:

$$dC_t/dt = NC_{in} - NC_t - k_a C_t L + k_d M L - k_{a1} C_t L_1 + k_{d1} M_1 L_1 \quad \dots\dots\dots (4.16)$$

Where k_a and k_d are the adsorption rate constant and the desorption rate constant for the room surfaces. L is the loading of the room and M is the mass of pollutants adsorbed per unit surface of the room. k_{a1} and k_{d1} are adsorption and desorption rate constant for painted gypsum board and L_1 and M_1 are the loading and the mass of pollutants adsorbed per unit area of painted gypsum board respectively.

The mass changes per unit surface area of the test samples and the room surfaces are described as:

$$dM_1/dt = k_{a1} C_t - k_{d1} M_1 \quad \dots\dots\dots (4.17)$$

$$dM/dt = k_a C_t - k_d M \quad \dots\dots\dots (4.18)$$

In this study, it was possible to estimate k_a , k_{a1} and k_d from the sensory assessments performed in the four rooms and by using different approaches. We know that when carpet is the pollution source, k_a and k_d are 0.06 m/h and 0.04 h⁻¹, respectively (see Table 4.3). Hence, for sorption to painted gypsum board $k_{a1} = 2.77$ m/h. It is apparent that the

surface removal for the room surfaces ($0.06 * 90 = 5.4 \text{ m}^3/\text{h}$) is much smaller than that for the painted gypsum board ($2.77 * 23 = 63.71 \text{ m}^3/\text{h}$). Hence, for carpet emissions sorption by room surfaces is negligible compared to sorption by the painted gypsum surface.

In an analogous manner, when linoleum was the pollution source: k_a , adsorption rate constant for the room surfaces = 0.42 m/h and the room surface removal rate = $0.42 * 90 = 37.8 \text{ m}^3/\text{h}$. The adsorption rate constant for the painted gypsum board $k_{a1} = 3.7 \text{ m/h}$ and the removal rate by the surface of painted gypsum board:

$k_{a1} * A = 3.7 * 23 = 85.1 \text{ m}^3/\text{h}$. Hence, for linoleum emissions sorption by the painted gypsum board still dominates that by room surfaces, but the two sinks are closer in value than was the case for carpet emissions.

Previous calculations have shown that the room surfaces played the role of sink for pollutants emitted from linoleum and carpet (see Table 4.3). In the case of carpet the room surfaces are a small sink in comparison to painted gypsum board. In the case of linoleum, the room surfaces are more important. Nonetheless, for simplification, the sink effect of the room surfaces will be neglected in Equation 4-16 so the original Tichenor Equation 4-6 will be applied on the sensory data from the room with painted gypsum board after the pollution source was taken out, as shown below. The effect of this assumption on the linoleum results will be discussed later.

4.3.2.1 Sorption parameters for painted gypsum board when carpet was the pollution source during sorption stage

Data from Experiment 3, Chapter 3 presented in Table 3.5 was used to calculate sorption parameters for the room with painted gypsum board during the desorption stage. Sensory

assessments results are shown in Table 4.8.

Table 4.8 Sensory assessments for the room with painted gypsum board just before and after the carpet samples were taken out

Time (after the materials were taken out of the room) (hrs)	Acceptability	Perceived air quality (decipol)
0	-0.09	8.1
4	0.00	5.1
24	0.02	4.6
48	0.07	3.5

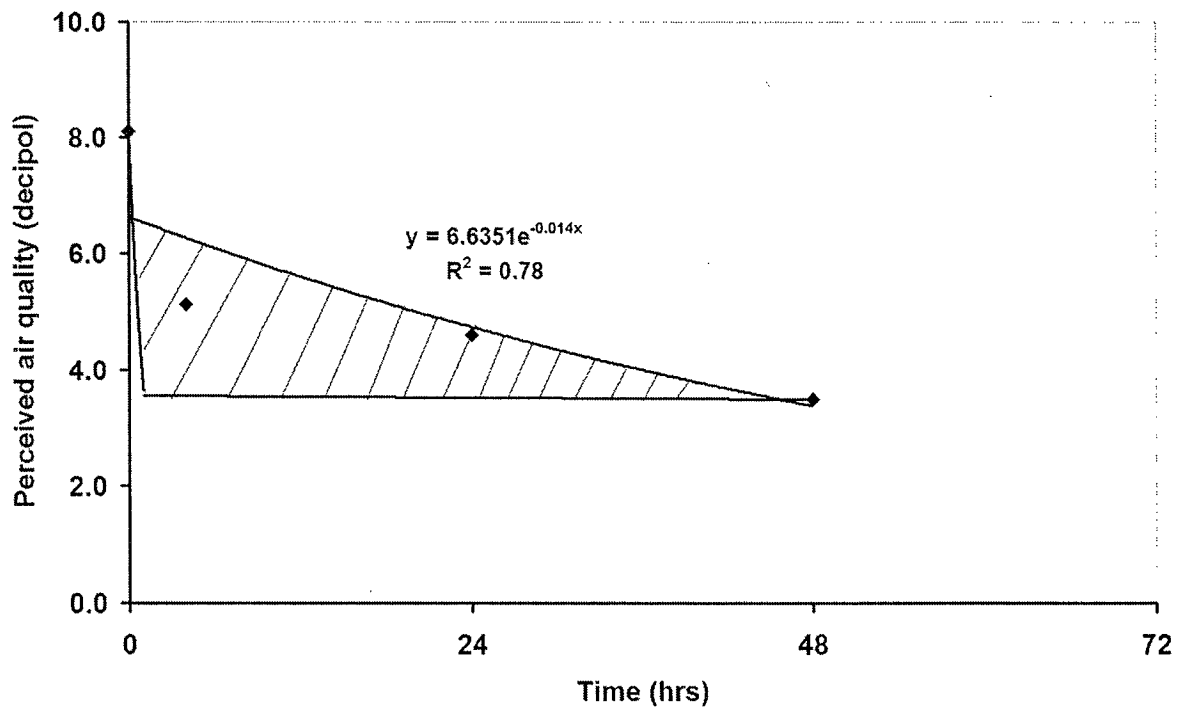


Figure 4. 5 Perceived air quality in the room that contained painted gypsum boards after the carpet was taken out (data include emission from painted gypsum board)

Figure 4.5 was used to calculate A_c (area under the curve) = 64.03 decipol *h

$$M_{e1} = (A_c * Q - C_e * V) / A$$

$$M_{e1} = ((78.32 * 32) - 8.1 * 40) / 23 = 110.56 \text{ decipol m}^3/\text{m}^2$$

$$K_{e1} = M_e/C_e = 110.56/8.1 = 13.63 \text{ m}$$

$$K_{e1} = k_a/k_d = 13.63 \text{ and } k_a = 9.26 k_d$$

$$r_1 = 2.17, \quad r_2 = 0.06$$

N : the air exchange rate in the room (h^{-1})

L_1 : loading factor and it is equal to (area of the painted gypsum board samples/volume of the room) = $23/40 = 0.575 \text{ m}^{-1}$

$$k_{d1} = 0.16 \text{ h}^{-1}, \quad k_{a1} = 2.2 \text{ m/h} \quad \text{and} \quad \text{Sum of errors} = 22.32$$

The measured perceived air quality shown in Table 4.8 includes the emission from painted gypsum board that was found (from another experiment) to be equal to 3 decipol after one week. Consequently, this value was subtracted from the ones shown in table 4-8 to exclude the emission from painted gypsum board, see Figure 4.6.

Figure 4.6 was used to calculate the new A_c (area under the curve) = $89.49 \text{ decipol} \cdot \text{h}$

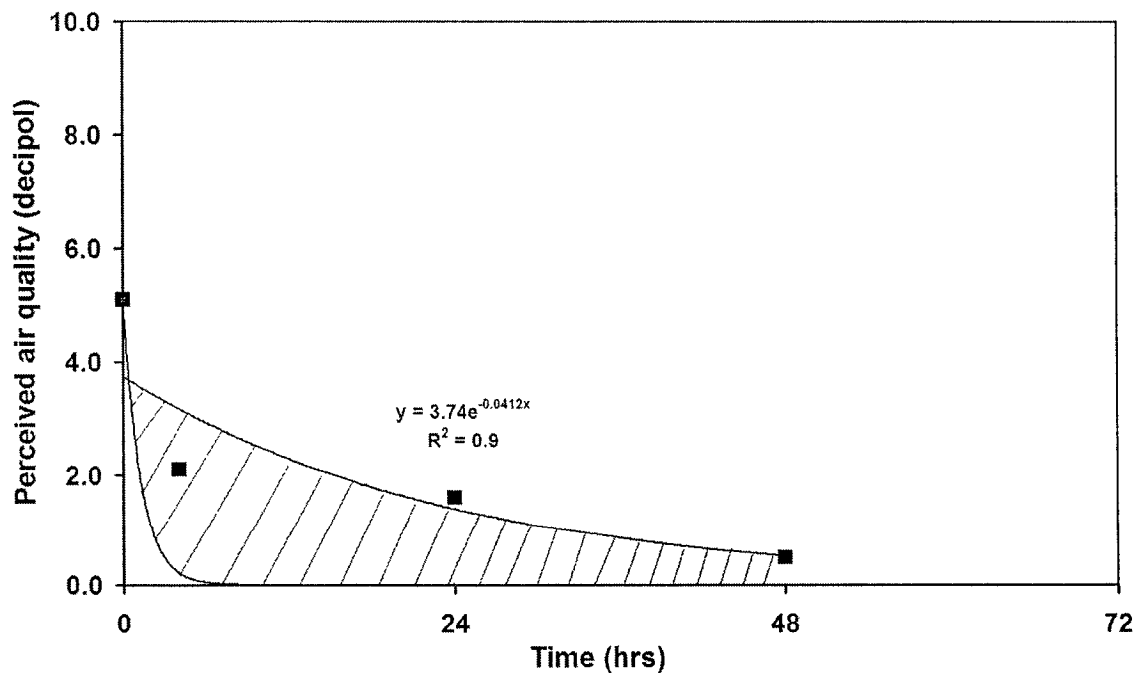


Figure 4. 6. Perceived air quality in the room that contained painted gypsum boards after the carpet was taken out and emission from painted gypsum boards was excluded

$$M_{e1} = ((A_c * Q) - C_e * V) / A$$

$$M_{e1} = ((89.49 * 32) - 5.1 * 40) / 23 = 115.64 \text{ decipol m}^3/\text{m}^2$$

$$K_{e1} = M_{e1} / C_{e1} = 115.64 / 5.1 = 22.68 \text{ m}$$

N: the air exchange rate in the room (h^{-1})

L_1 : loading factor and it is equal to (area of painted gypsum board samples/volume of the room) = $23/40 = 0.575 \text{ m}^{-1}$

$$k_{d1} = 0.05 \text{ h}^{-1}, \quad k_{a1} = 1.2 \text{ m/h}, \quad \text{Sum of errors} = 0.15$$

4.3.2.2 Sorption parameters for painted gypsum board when linoleum was the pollution source during sorption stage

In Experiment 5, Chapter 3, linoleum and painted gypsum boards were placed together in the same room for one week then linoleum was taken out of the room and sensory assessments were performed after 4, 24, 48, and 72 hrs. The results of these sensory assessments are shown in Table 4.9. Again the values shown in the table include the emission from painted gypsum board and to exclude its effect 3 decipols (that present the emission from painted gypsum board after it has been placed in a ventilated room for one week) was subtracted from the measured perceived air quality.

Table 4.9 Sensory assessments for the room with painted gypsum boards after linoleum was taken out i.e. during desorption stage

Time (after the materials were taken out of the room) (hrs)	Acceptability	Perceived air quality (decipol)
0	-0.11	8.8
4	-0.01	5.4
24	0.014	4.8
48	0.08	3.3
72	0.09	3.1

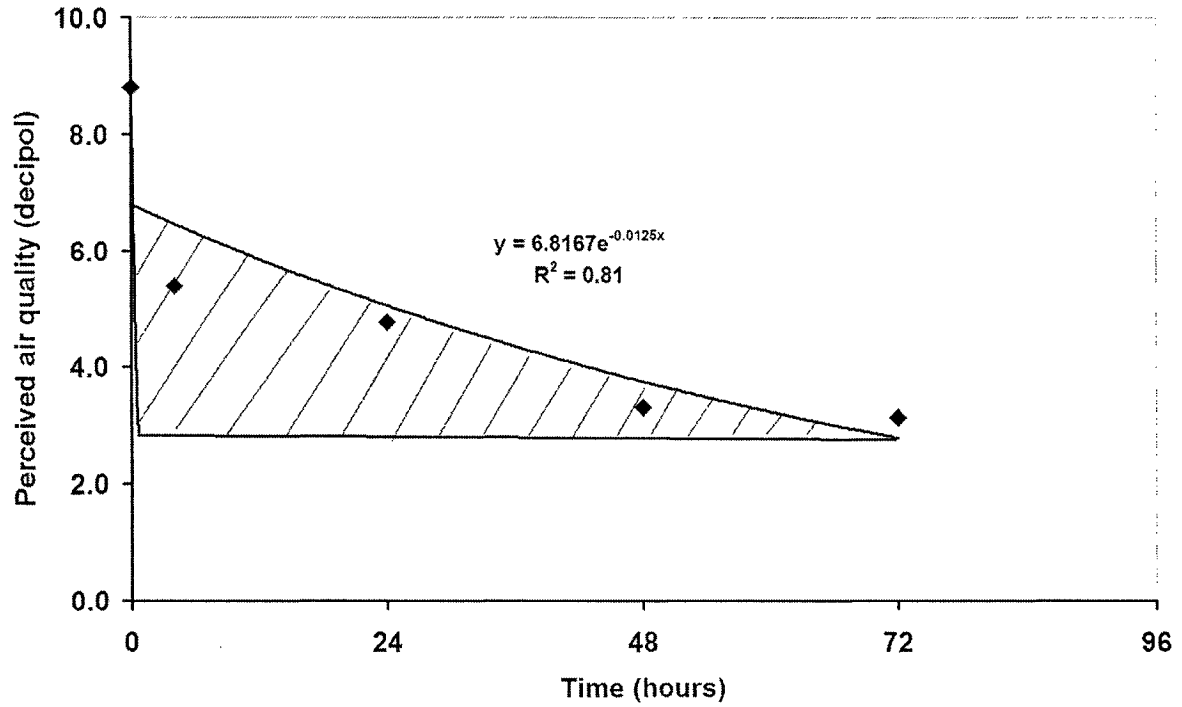


Figure 4.7 Perceived air quality in the room with painted gypsum boards after the linoleum was taken out (data include emission from painted gypsum board)

Figure 4.7 was used to calculate the area under the curve (A_c)

$$A_c = 108 \text{ decipol} \cdot \text{hr}$$

$$M_e = 134.96 \text{ decipol} \cdot \text{m}$$

$$K_e = 15.34 \text{ m}$$

$$r_1 = 2.28, \quad r_2 = 0.087$$

$$k_{dl} = 0.12 \text{ h}^{-1}, \quad k_{al} = 1.9 \text{ m/h}$$

To account for the emission from painted gypsum board, three decipols were subtracted from the perceived air quality measured in the room with painted gypsum after the linoleum was taken out of the room. And sorption parameters for painted gypsum board were recalculated.

Figure 4.8 was used to calculate the area under the curve (A_c)

$$A_c = 83.72 \text{ decipol} \cdot \text{hr}$$

$$M_{e1} = 106.4 \text{ decipol} \cdot \text{m}$$

$$K_{e1} = 18.34 \text{ m}$$

$$k_{d1} = 0.07 \text{ h}^{-1}, \quad k_{a1} = 1.26 \text{ m/h}, \quad \text{Sum of errors} = 0.4$$

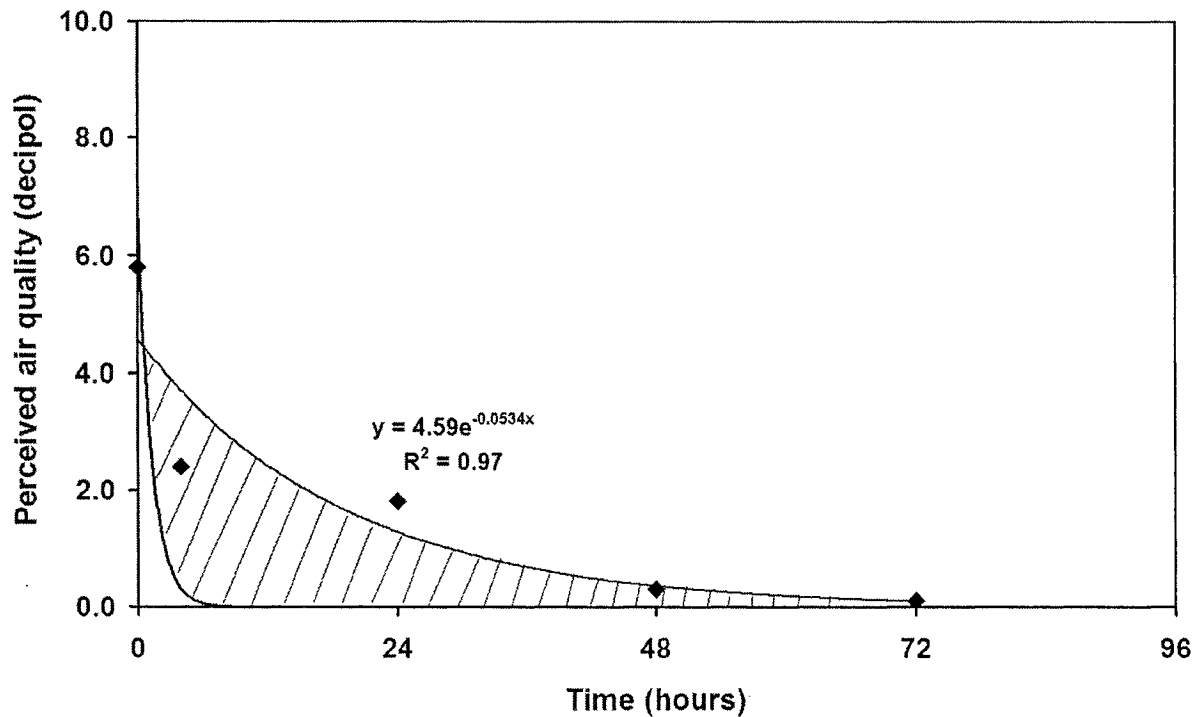


Figure 4. 8 Perceived air quality in the room with painted gypsum boards after the linoleum was taken out

Sorption parameters for the room surfaces and painted gypsum boards calculated when the pollution source was either carpet or linoleum and for the two cases: when the emission from painted gypsum board was taken into account and when it was ignored are summarized in table 4.10.

Table 4.10 Summary of the results: sorption parameters for the room surfaces and for painted gypsum board

	Pollution source	k_a, k_{a1} (m/h)	k_d, k_{d1} (h ⁻¹)	K_e, K_{e1} (m)	M_e, M_{e1} (decipol* m ³ /m ²)
For room surfaces	Carpet	0.06	0.04	1.5	28
	Linoleum	0.42	0.11	3.8	73
For painted gypsum board. Data from adsorption phase	Carpet				
	- Experiment1	2.5			
	- Experiment2	3.1			
	Linoleum	3.7			
For painted gypsum board using desorption data and Tichenor model					
	1. When the data included the emission from PGB				
	Carpet	2.2	0.16	13.7	111
	Linoleum	1.9	0.12	15.3	135
	2. When the emission was subtracted from the sensory data				
	Carpet	1.2	0.05	23	116
	Linoleum	1.3	0.07	18	106

4.4 Sorption parameters for Semia

4.4.1 Adsorption rate constant for Semia

Semia and linoleum were tested individually and in combination, see Experiment 6, Chapter 3. From the sensory assessments performed 4 hrs after the materials were placed inside the rooms i.e. at sorption stage and by using Equations (4.12) (4.13) (4.15) the adsorption rate constant for Semia was calculated as shown in Table 4.11. The resulting value, 62 m/h is unrealistically high. It is significantly larger than the predicted transport

Table 4.11 Calculation of adsorption rate constant for Semia ($k_{a \text{ semia}}$) using sensory assessments from Experiment 6, Chapter3, when linoleum was used as the pollution source.

Time (hrs)	$C_{(L)}$ (Linoleum) (decipol) (1)	$C_{(Semia)}$ (decipol) (2)	$C_p =$ (1)+(2) (3)	$Q^* = Q + k_{a \text{ room}}^{(2)} \cdot A_{\text{room}}$ (4)	Q m^3/h (5)	C_m (decipol) (6)	C_m/C_p (7)	$(4)/(7)$ (8)	$(8)-(4)$ (9)	A (m^2) (10)	$k_{a \text{ Semia}}$ (m/h) (11)
4	18.7	0.72	19.39	69.8	32	0.85	0.044	1591.67	1521.87	24.5	62.12

$k_{a \text{ room}}^{(2)} = 0.42 \text{ m}/\text{h}$ (adsorption rate constant for room surfaces when linoleum was the pollution source; see Table 4.3)

limited rate of adsorption (Nazaroff et al.,1993). Presumably this reflects the fact that the actual surface area of Semia (the area of the activated charcoal impregnated in the fabric) Is much larger than its projected surface area (24.5 m^2). For example, if the actual surface area of Semia were 100 times larger than the projected surface area (not unrealistic), the re-calculated value for $k_a \text{ Semia}$ would be 0.62 m/h . Unfortunately, the actual surface area for Semia is not known. Special experiment, beyond the scope of the present thesis, would be necessary to determine this value.

4.4.2 Sorption parameters for Semia based on data from desorption stage

The adsorption rate constant (k_a) for Semia, calculated from sorption stage indicates the high sorption capacity of this material in comparison with the room surfaces when linoleum was the pollution source. It was found that for Semia, $k_a \text{ Semia} = 62 \text{ m/h}$ while for the room surfaces, $k_a \text{ room surfaces} = 0.42 \text{ m/h}$. One could try to estimate, sorption parameters for Semia based on the sensory data from Experiment 6, Chapter 3, during the desorption stage (after the linoleum was taken out of the room). However, in this case the approach would not give valid results. The system containing Semia has not reached equilibrium. This is apparent if the perceived air quality at the moment that the linoleum is taken out of the Semia containing room is compared to that measured after a week when linoleum was in a room without Semia (2.5 decipol versus 19.1 decipols). If the Semia containing system had been in equilibrium, these sensory assessments should have given roughly similar results. If the model is applied on the data in Table 4.12, the results will be more indicative of what is happening on the room surfaces rather than what is

happening on the surface of Semia. This is demonstrated with the following calculation, made in a manner analogous to earlier “desorption stage” calculations.

The results of sensory assessments performed during desorption stage Experiment 6 are summarized in table 4.12.

Table 4.12 Sensory assessments for the room with Semia after linoleum was taken out i.e during desorption stage

Time (after the materials were taken out of the room) (hrs)	Acceptability	Perceived air quality (decipol)
0	0.13	2.5
4	0.21	1.6
24	0.24	1.3
48	0.34	0.8
72	0.30	0.9

The sensory data for the room with Semia during desorption stage is presented in Figure 4.7 as well. Desorption is represented by the hatched area.

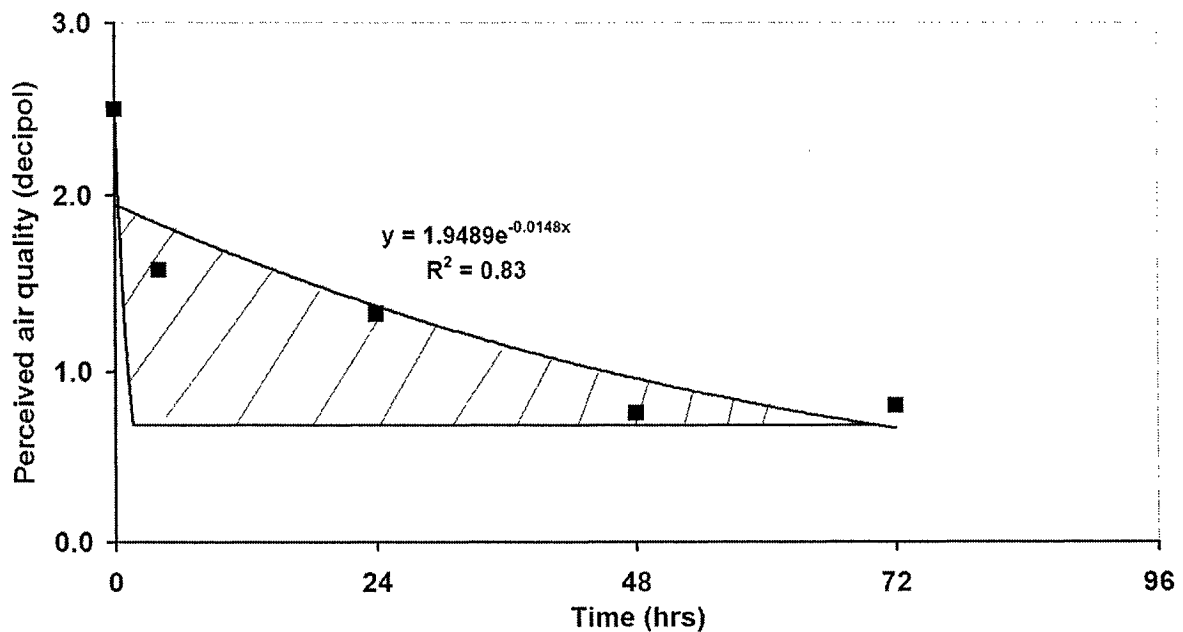


Figure 4.9 Perceived air quality in a room with Semia after the linoleum was taken out

Sorption and desorption rate constants were estimated from the measured perceived air quality in the test room by least square regression method.

The calculation results are summarized as follow:

$$A_e = 36 \text{ decipol*hr} , \quad M_e = 42.94 \text{ decipol m}^3/\text{m}^2 , \quad K_e = 17.18 \text{ m}$$

$$r_1 = 2.25 , \quad r_2 = 0.046$$

$$k_a = 2.23 \text{ m/h} , \quad k_d = 0.13 \text{ h}^{-1}$$

k_d for Semia is similar to that measured for linoleum desorbing from room surfaces (see Table 4.3). Indeed, during the desorption phase of the Semia experiment most of the desorption is anticipated to have come from the room surfaces and very little desorption is anticipated to have come from the activated charcoal that constituted the Semia.

4.5 Discussion

Sorption parameters for the test room surfaces, for painted gypsum board and for Semia were estimated based on sensory data from either the sorption or desorption stage. Two different approaches were applied depending on the stage in which the assessments were made. In these sorption experiments carpet and linoleum were used as the pollution sources.

4.5.1 Sorption parameters for the room surfaces:

The adsorption rate coefficient, k_a , for the room surfaces was estimated using two different approaches. The first approach is based on the mass balance considerations in the test rooms and it was applied to early sensory assessments for the mixing room during the sorption stage. The second approach is based on Tichenor model and it was applied

on sensory data from desorption stage. The second approach allowed for the calculation of other sorption parameters as well. The values of adsorption rate constant for the room surfaces k_a obtained from the two approaches were almost the same, and indicated that the room surfaces act as moderate sinks for pollutants emitted from carpet. The capability of a sink material to adsorb indoor air pollutants is represented by the surface/air equilibrium partition coefficient, K_e . The higher the value of K_e , the greater the amount of pollutant adsorbed on the sink (i.e., the stronger the sink).

The results summarized in Table 4.3 show that K_e for the room surfaces was different for the two different pollution sources used in the experiments (linoleum and carpet). K_e was larger for emissions from linoleum than from carpet indicating that the room surfaces are a stronger sink for the compounds emitted from linoleum than the ones emitted from carpet. The nature of the chemicals emitted from linoleum might be the reason, as they tend to be more polar than the chemicals emitted from carpet. Most of the indoor surfaces are moderately polar and, as they age, they oxidize and become increasingly polar (Weschler, 2003). Consequently, room surfaces are expected to adsorb the more polar compounds more strongly.

4.5.2 Sorption parameters for painted gypsum board:

To quantify adsorption rate coefficients for painted gypsum board from the sorption stage data, sensory assessments made during the first few hours that the two materials were in the room were used. The calculations excluded the impact of the room surfaces by taking $k_{a \text{ room}}$ into account. With carpet as the pollution source, results calculated using data from two different experiments performed with different panels at different time of the year

yielded almost the same value for k_a to the gypsum board (2.44 m/h and 3.06 m/h). With linoleum as the pollution source, the same procedure yielded an adsorption rate coefficient to the painted gypsum board of 3.7 m/h. This is larger than the value found using the same panel for the assessments when carpet was the pollution source (2.44 m/h). These two values were obtained not only using the same panel, but the assessments were performed at almost the same time (one week interval) and using the same test materials and the same room conditions. Hence, direct comparisons between these two values should be quite valid. These values for k_a _{PGB} carry some errors as a result of neglecting the sink impact due to either carpet or linoleum when they were placed together with the painted gypsum board. The difference between the sink behavior of carpet and linoleum could influence the calculated values of k_a for painted gypsum board. Another factor that is expected to play a larger role is the difference in the chemical nature of the pollutants emitted from the two different pollution sources. For the same reasons that were discussed for the room surfaces, one would expect linoleum emissions to have a larger k_a to the surface of painted gypsum boards than the carpet emissions.

Adsorption rate coefficients for painted gypsum board were also calculated, together with the other sorption parameters, using data from the desorption stage by applying Tichenor model. The impact of the emission from painted gypsum board on the perceived air quality was subtracted from all assessments performed after the source of pollution (carpet or linoleum) was taken out of the room. The results showed similar values for painted gypsum sorption parameters when either carpet or linoleum was used as source of pollution, (see table 4.10). However, and as mentioned earlier, the room surfaces were a stronger sink for the emissions from linoleum ($K_e = 3.8$ m) than the emissions from

carpet ($K_e = 1.48 \text{ m}$). Neglecting the sink effect of the room surfaces introduces some error into the value of $K_{e \text{ PGB}}$ calculated when linoleum was used as the source of pollution, and this could result in a larger calculated value for $K_{e \text{ PGB}}$ than is actually correct. Another point to consider is the equilibrium concentration C_e , which, in this study was assumed to be reached after one week for the two different sources of pollution used in these experiment. This assumption could also be the source of some error in the estimated value of K_e if equilibrium had not been reached.

4.5.3 Sorption parameters for Semia:

An adsorption rate coefficient was also calculated for Semia when tested with linoleum based on the first sensory assessment performed after placing the two materials together. The calculated value of $k_{a \text{ Semia}} = 62 \text{ m/h}$ was much larger than the one for painted gypsum board and the one for the room surfaces. This may partially reflect the fact that the actual sorbing area of the Semia is much larger than the projected area of Semia used in the calculation. The Tichenor model was also applied to the data obtained from the desorption stage (after linoleum was taken out of the room). M_e , the mass adsorbed at equilibrium per unit area of Semia was relatively small ($M_e = 43 \text{ decipol m}^3/\text{m}^2$). This is most likely not a correct value due to the relatively short time of this experiment (one week); given the large sorbing area (and sorbing capacity) for Semia, one week was probably insufficient for the system to reach equilibrium. Another factor to consider is that sorption to Semia may be somewhat non-reversible. The Tichenor model, is based on the first order reversible adsorption/desorption Langmuir isotherm, and is not appropriate for a system in which irreversible adsorption occurs. However, the calculated sorption parameters for Semia, although inaccurate, at least are indicative of Semia's ability to act

as a sink in an indoor setting. The experiments conducted as part of this thesis demonstrate that, at least over a one-week period, Semia is an exceedingly strong sink for linoleum emissions. Indeed, it is such a strong sink that the room containing Semia and linoleum had assessed air quality that was almost as good as an empty room.

Table 4-13 shows some of the results from previous studies that aimed to investigate the sink effect of painted gypsum board by testing it with different chemicals. The same linear sink model (Tichenor model) used in this study was used in the referenced studies.

Table 4.13. Selected sorption data from peer-reviewed literature (analyzed by linear Langmuir model) for cases where painted gypsum board was used as a sink.

Method	Reference	Pollution source	Ads. Coeff. k_a (m/h)	Des. Coeff. k_d (h ⁻¹)	Equil. Coeff. K_e (m)
Sensory	The present study	Carpet	1.2	0.05	24
		Linoleum	1.3	0.07	19
Chemical	Won, Corsi & Rynes (1999)	Iso-propyl alcohol (IPA)	0.08	0.24	0.33
		Tetrachloroethene (PCE)	0.06	0.45	0.13
		o-dichlorobenzene (DCB)	0.26	0.25	1.04
		1,2,4-trichlorobenzene	0.5	0.29	1.72
	Popa & Haghghat (2003)	Iso-propyl alcohol (IPA)	0.43	2.67	0.16
		Methyl ethyl ketone (MEK)	0.05	0.47	0.11
		Perchloroethylene (PCE)	1.1	5.52	0.2

Although a strict comparison between results from previous studies and the present one is not feasible due to the lack of a common comparison base, Table 4-13 is useful as a demonstration of the different behavior of a sink (the painted gypsum board in the present study) when exposed to realistic conditions (air polluted by hundreds of chemicals emitted from other building materials) compared to when it is exposed to an artificial environment (air polluted by one or several VOCs with concentrations usually higher than the ones found in a real indoor environment).

The large values for the room surfaces and the painted gypsum board equilibrium partition coefficient (K_e) found in this study could be explained by the fact that the compounds that chiefly affect sensory assessments of the indoor air quality usually have different physicochemical properties than the volatile organic compounds that have been routinely used in sorption experiments. These properties include solubility and octanol-air partition coefficient (Cometto-Muniz and Cain, 1994; Won et al., 2001) and vapor pressure/molecular size (within a homologous series, compounds with higher molecular weight can be perceived at lower concentrations, Cometto-Muniz and Cain 1995, Abraham et al. 1998, Weschler 2003). In general, the compounds that elicit a sensory response are expected to have smaller k_d 's and larger K_e 's than those reported for the smaller volatile organic compounds that have been investigated in previous sorption experiments.

Weschler 2003, explained the relationship between the molecular weight and nasal pungency. He reported that the sensation of nasal pungency produced by a short-term sniff occurs only when the gas phase concentration exceeds 10% of its maximum value which means that for small molecules, the concentration required to produce a pungency

response is very high (higher than what typically found in indoor environment) and only large molecules could approach concentrations necessary to elicit a pungency response. On other hand, the same paper showed a linear relationship between log saturated vapor pressure of a compound and its molecular weight (large molecules have lower saturated vapor pressures). As it is well documented that compounds with lower saturated vapor pressures tend to be adsorbed more (Kephelopoulos et al. 1996, Van der Waal et al. 1998, An et al. 1999, Won et al. 2001), the molecular weight (a simple property of a compound), can be used to obtain a rough estimate of a compound's tendency to be adsorbed by the different surfaces.

It is important to point out that the chemicals addressed in this study are specifically the ones that evoke a sensory response and that the methods used work only if this set of chemicals have relatively similar adsorption and desorption constants. In all of the performed experiments with different pollutions sources and sinks, the calculated k_a (or k_d) for each source-sink combination represents a “grand aggregate” value for the sorption constant. This only works if the chemicals responsible for eliciting a sensory response for a given material have almost the same k_a 's (or k_d 's). In this work, based on sensory data, it was possible to get reasonable values for sorption parameters for painted gypsum board and the room surfaces presumably because the chemicals emitted from the carpet (or linoleum) used in the experiments are relatively similar in terms of their sorption parameters. Otherwise, the method used in this study would not be valid. For instance, it is not expected that the same method applied in the present study would be valid if tobacco smoke were used as a pollution source. Although many of the different chemicals emitted from a cigarette could be measured by sensory evaluations, the

differences among the sorption parameters of these components make it impossible to derive informative data on the sink's sorption properties. To state it more explicitly, some of the tobacco smoke emissions that humans sense are small molecules and some are much larger molecules; these molecules have quite different k_a 's (and k_d 's); an approach that uses sensory assessments to derive one overall value for k_a (or k_d) will not work in such a case.

Another important point to be mentioned is that the Langmuir model used by Tichenor and applied in this work, assumes that sorption happens only on the material surface (ignoring diffusion into the material). This assumption may not always be met in reality, especially for porous materials. It is expected that after some time, the compounds adsorbed on the surface of a porous material will diffuse into the interior of the material. Therefore, the Langmuir model may not be suitable when diffusion is dominant (eg. sorption on carpet) (Tichenor et al., 1991, Zhang et al., 2001).

Bearing in mind the above caveats, this work has demonstrated that sensory assessments can be used to derive sorption parameters for common indoor pollution sources interacting with common indoor surfaces. Most of the chemicals detected by the human subjects in these experiments were present at concentrations too low to be measured by traditional chemical methods. Hence, sensory assessments were able to provide information on sorption processes that could not have been obtained by chemical means. The resulting information is of direct relevance to perceived air quality since the chemicals "measured" by the human subjects are the very ones that influence their overall assessment of the acceptability of the air that surrounds them.

CHAPTER 5

5.1 CONCLUSIONS

Seven experiments were performed in real offices using either carpet or linoleum as pollution source and painted gypsum boards and the room surfaces as sinks. Moreover Semia, a sorbing material consisting of activated charcoal was also tested when linoleum was the pollution source. The aim was to investigate the impact of sorption on perceived indoor air quality. Each experiment lasted between one week (for experiments aimed to study adsorption stage only) and ten days (for experiments that studied adsorption and desorption stages). An untrained sensory panel composed of different numbers of subjects assessed the air quality in the rooms using an acceptability scale. Sensory evaluations were performed at specific time after moving the materials into or out of the rooms depending on the design of each experiment and following a randomized plan that was different for different subjects and different days. To quantify the impact of sorption phenomena sorption parameters for the room surfaces, painted gypsum board and Semia were estimated based on the experimental results and using Langmuir model as proposed by Tichenor et al. 1991. These calculations permitted comparisons among the different materials when exposed to different pollution sources. Based on the results of this study the following conclusions could be drawn:

- Sorption affects the perceived air quality significantly. The magnitude of this impact depends on the kind of pollution sources and on the area and nature of the sink.
- Sensory measurements can be used to study sorption phenomena in real indoor environments, where different building materials co-exist with different kinds of air pollutants. It overcomes some of the limitations associated with conventional chemical methods.

- The use of the Langmuir model as proposed by Tichenor et al. (1991), and based on the results of sensory assessments performed in this study, it was possible to estimate the sorption parameters for the room surfaces and for painted gypsum board. The model appeared to be suitable for these two sinks. However, for other surfaces, when diffusion is dominant (e.g. sorption on carpet) the Langmuir model may not be convenient.
- The results demonstrate a higher sink effect for the room surfaces when linoleum was the pollution source than when carpet was the source of pollution. In turn, painted gypsum board was found to be a stronger sink than the room surfaces for the two different pollution sources (carpet, linoleum).
- The relatively large values of equilibrium partition coefficients calculated for the room surfaces and the painted gypsum boards indicate that the compounds sorbed on the studied surfaces have high molecular weights and low saturation vapour pressures. Since the “instrument” used to derive these sorption parameters is sensory assessment, this information tells us something about the chemical properties of the emissions that are responsible for sensory effects. As anticipated, these are not chemicals that would be classified as volatile organic compounds (VOCs). The derived sorption parameters indicate that the chemicals responsible for the sensory responses are larger and more complex than the so-called VOCs.
- The results from the Semia experiment demonstrate an application where the sorption phenomenon is used to improve the perceived air quality indoors. However, questions remain concerning the period of time during which such a product would remain effective.

5.2 Practical implication of this study

The results of the present work demonstrate the significant impact of sorption phenomena on perceived indoor air quality. When two materials were placed together in the same room, the air was perceived to be better than the air polluted by the more polluting material. The pollutants emitted from one building material were adsorbed on the other, reducing the concentration of pollutants and improving the quality of the perceived air for that room. However, the subsequent slow desorption prolongs the presence of the pollutants in that room even after the elimination of the source, which leaves the question of whether the presence of sorbent materials has a negative or positive effect on the perceived air quality. The limited available data indicate that the influence can be both negative and positive. However, given the accumulation of pollutants over time, sorption appears to be, on balance, negative. Sorption converts materials capable of adsorbing pollutants to reservoirs of pollutants that will act as sources whenever the equilibrium conditions are changed in such a way that the room air concentration no longer supports the surface concentration. As long as, there is insufficient data on the nature of different sinks in real rooms and on how to control the equilibrium conditions for different materials found indoors, would be imprudent to consider the impact of sorption as being positive. On the other hand, a material such as Semia might be used in a deliberate way to sorb sources during periods when a room is occupied and then the material might be “regenerated” when the room is not occupied.

This study opens the door for a new method of studying sorption phenomena in real rooms. The method allows for derivation of sorption parameters for common indoor pollution sources interacting with common indoor surfaces, based on assessments performed by human subjects. Despite the limitations discussed in the previous chapter and until another method

becomes available, sensory evaluations could be used to study sorption impact on perceived air quality in real life environments. Many questions related to sorption phenomena and the impact of sorption on air quality still without answers and need to be investigated. Below are some suggestions for future work based on the results of the present research.

5.3 Recommendations for Future work

- Additional experiments should be conducted using human beings as sources of indoor pollution to investigate the extent to which indoor materials act as a sink for human bioeffluents.
- It would be useful to separate the sink and the source, i.e., to test the sink effect of a building material by exposing it to an air polluted by another building material without that material being present. Such a separation prevents the source from behaving as a sink and reduces the error on estimated sorption parameters.
- The sink effect of building materials, other than the ones used in this work, and which are typically found indoors should be tested using the same procedure. There is a need to collect data on the sorption characteristic of different materials used indoors. Materials should be classified not only regarding to their emission but also to their ability to adsorb and desorb indoor pollutants
- The impact of the area of the sink, the ventilation rate and the environmental conditions on the materials that act as a sink, should be investigated more using sensory assessments.

- Semia should be tested for a longer time (until equilibrium is reached). At such a point, the pollution source could be taken out to investigate to what extent is the sorption on Semia reversible and “loaded” Semia becomes a pollution source.
- It is recommended to revisit previous studies where sorption was not taken into account. As shown in the present work, sorption can significantly change the sensory pollution load caused by different pollution sources located in the same room.

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Appendix A

Statistical analysis for the data obtained from the seven performed experiments

Wilcoxon matched pairs test

This test is a nonparametric test and it is alternative to the t-test for dependent (correlated) samples. Variables will be specified in two lists. Each variable from the first list will be compared with each variable from the second list. This is the same arrangement of data that is expected for the t-test (dependent samples) in the Basic Statistics module. The procedure assumes that the variables under consideration were measured on a scale that allows the rank ordering of observations based on each variable and that allows rank ordering of the differences between variables.

If the assumptions for the parametric t-test for dependent samples (interval scale) are met, then this test is almost as powerful as the t-test.

Friedman test

Friedman ANOVA is a nonparametric alternative to one-way repeated measures analysis of variance. The procedure expects the data to be arranged in the same way as one would arrange a data file for a within-subjects (repeated measures) analysis of variance with ANOVA/MANOVA. Specifically, the values for each level of the repeated measures factor should be contained in a different variable. The Friedman ANOVA by ranks test assumes that the variables (levels) under consideration were measured on at least an ordinal (rank order) scale. The null hypothesis for the procedure is that the different columns of data contain samples drawn from the same population, or specifically, populations with identical medians. Thus, the interpretation of results from this procedure is similar to that of a repeated measures ANOVA.

Experiment 1 Carpet and painted gypsum board

Time		Valid N	Mean	Confid.		Minimum	Maximum	Std.Dev.	Standard Error
				-95.000%	+95.000%				
4 hrs	Room1 (empty)	16	0.341	0.141	0.540	-0.25	0.78	0.374	0.094
	Room2 (empty)	16	0.188	-0.042	0.417	-0.43	0.90	0.430	0.108
	Room3 (empty)	16	0.402	0.206	0.597	-0.45	1.00	0.367	0.092
	Painted gypsum board	17	0.034	-0.185	0.253	-0.68	0.75	0.426	0.103
	Carpet	17	-0.275	-0.441	-0.109	-0.88	0.20	0.324	0.079
24hrs	Carpet+ painted gypsum board	17	0.050	-0.139	0.239	-0.63	1.00	0.367	0.089
	Painted gypsum board	17	0.034	-0.185	0.253	-0.68	0.75	0.426	0.103
	Carpet	17	-0.275	-0.441	-0.109	-0.88	0.20	0.324	0.079
120hrs	Carpet+ painted gypsum board	17	0.050	-0.139	0.239	-0.63	1.00	0.367	0.089
	Painted gypsum board	16	0.059	-0.190	0.308	-0.90	0.95	0.467	0.117
	Carpet	16	-0.264	-0.493	-0.035	-1.00	0.73	0.430	0.107
	Carpet+ painted gypsum board	16	-0.220	-0.478	0.037	-0.93	0.98	0.483	0.121

Wilcoxon Matched Pairs Test (exp.1)

Time		Valid			
		N	T	Z	p-level
4 hrs	Carpet vs carpet and painted gypsum board	17	1	3.46449	0.00053
24hrs	Carpet vs carpet and painted gypsum board	17	15	2.74056	0.00614
120hrs	Carpet vs carpet and painted gypsum board	16	45.5	0.43944	0.66035

Friedman ANOVA and Kendall Coeff. of Concordance (exp.1)					
ANOVA Chi Sqr. (N = 16, df = 2) = 1.193548 p < .55059					
Coeff. of Concordance = .03730 Aver. rank r = -.0269					
Time (hrs)		Average Rank	Sum of Ranks	Mean	Std.Dev.
4hrs	Carpet	1.78125	28.5	-0.4313	0.33398
24hrs	Carpet	2.125	34	-0.2766	0.33435
120hrs	Carpet	2.09375	33.5	-0.2641	0.42992

Friedman ANOVA and Kendall Coeff. of Concordance (exp.1)					
ANOVA Chi Sqr. (N = 16, df = 2) = 5.375000 p < .06807					
Coeff. of Concordance = .16797 Aver. rank r = .11250					
Time (hrs)		Average Rank	Sum of Ranks	Mean	Std.Dev.
4hrs	carpet and painted gypsum board	2.375	38	0.14063	0.45377
24hrs	carpet and painted gypsum board	2.0625	33	0.05625	0.37832
120hrs	carpet and painted gypsum board	1.5625	25	-0.2203	0.48306

Experiment 2

Carpet and painted gypsum board Descriptive Statistics (new.sta)

Time		Valid N	Mean	Confid. -95.000%	Confid. +95.000%	Minimum	Maximum	Std.Dev.	Standard Error
	Room 1(empty)	13	0.279	0.087	0.471	-0.18	0.83	0.317	0.088
	Room 2(empty)	13	0.248	0.037	0.460	-0.23	0.90	0.350	0.097
	Room 3(empty)	13	0.296	0.154	0.439	-0.10	0.63	0.236	0.065
	Room 4(empty)	13	0.400	0.202	0.598	-0.38	0.90	0.328	0.091
4 hrs	Painted gypsum board	15	-0.068	-0.255	0.119	-0.45	0.65	0.338	0.087
	Mixing room	15	-0.102	-0.290	0.086	-0.78	0.80	0.340	0.088
	Carpet	15	-0.337	-0.517	-0.157	-0.93	0.18	0.325	0.084
	Carpet+ painted gypsum board	15	-0.127	-0.284	0.031	-0.50	0.60	0.284	0.073
8hrs	Painted gypsum board	15	-0.002	-0.125	0.122	-0.38	0.40	0.224	0.058
	Mixing room	15	-0.127	-0.333	0.080	-0.68	0.75	0.373	0.096
	Carpet	15	-0.228	-0.461	0.004	-0.98	0.48	0.420	0.108
	Carpet+ painted gypsum board	15	0.028	-0.184	0.240	-0.55	0.85	0.383	0.099
24hrs	Painted gypsum board	13	0.002	-0.181	0.185	-0.43	0.58	0.303	0.084
	Mixing room	13	-0.223	-0.458	0.012	-0.85	0.50	0.389	0.108
	Carpet	13	-0.408	-0.669	-0.146	-0.95	0.25	0.433	0.120
	Carpet+ painted gypsum board	13	-0.142	-0.443	0.158	-0.90	0.58	0.497	0.138
48hrs	Painted gypsum board	15	0.023	-0.203	0.250	-0.63	0.75	0.409	0.106
	Mixing room	15	-0.200	-0.409	0.009	-0.90	0.43	0.378	0.098
	Carpet	15	-0.483	-0.675	-0.292	-0.90	0.20	0.346	0.089
	Carpet+ painted gypsum board	15	-0.137	-0.344	0.071	-0.73	0.73	0.375	0.097
72hrs	Painted gypsum board	12	-0.069	-0.249	0.111	-0.48	0.58	0.284	0.082
	Mixing room	12	-0.133	-0.348	0.081	-0.58	0.65	0.337	0.097
	Carpet	12	-0.475	-0.705	-0.245	-0.98	0.23	0.363	0.105
	Carpet+ painted gypsum board	12	-0.062	-0.331	0.206	-0.88	0.65	0.423	0.122
144hrs	Painted gypsum board	15	-0.052	-0.321	0.218	-0.73	0.95	0.487	0.126
	Mixing room	15	-0.173	-0.393	0.047	-0.93	0.70	0.397	0.103
	Carpet	15	-0.470	-0.669	-0.271	-0.90	0.18	0.360	0.093
	Carpet+ painted gypsum board	15	-0.132	-0.343	0.080	-0.58	0.78	0.382	0.099
168hrs	Painted gypsum board	11	-0.111	-0.321	0.098	-0.65	0.35	0.312	0.094
	Mixing room	11	-0.168	-0.389	0.053	-0.83	0.38	0.329	0.099
	Carpet	11	-0.470	-0.678	-0.263	-0.90	0.10	0.308	0.093
	Carpet+ painted gypsum board	11	-0.145	-0.502	0.211	-0.83	0.93	0.530	0.160

Wilcoxon Matched Pairs Test (exp.2)

Time	Compared rooms	Valid N	T	Z	p-level
4 hrs	Carpet & mixing exhausts	15	22	2.1583	0.0309
	Carpet & Combined materials	15	3	3.2374	0.0012
	mixing exhausts&combined materials	15	52	0.0314	0.9750
8hrs	Carpet & mixing exhausts	15	45	0.8519	0.3943
	Carpet & Combined materials	15	15	2.3541	0.0186
	mixing exhausts&combined materials	15	28	1.8175	0.0692
24hrs	Carpet & mixing exhausts	13	15	2.1315	0.0331
	Carpet & Combined materials	13	16	2.0616	0.0393
	mixing exhausts&combined materials	13	37	0.5940	0.5525
48hrs	Carpet & mixing exhausts	15	16	2.4990	0.0125
	Carpet & Combined materials	15	2	3.2942	0.0010
	mixing exhausts&combined materials	15	46	0.7951	0.4265
72hrs	Carpet & mixing exhausts	12	7	2.510	0.0121
	Carpet & Combined materials	12	0	3.059	0.00222
	mixing exhausts&combined materials	12	20	1.156	0.2478
144hrs	Carpet & mixing exhausts	15	16	2.499	0.0125
	Carpet & Combined materials	15	12	2.726	0.0064
	mixing exhausts&combined materials	15	48.5	0.251106	0.801734
168hrs	Carpet & mixing exhausts	11	8.5	2.178316	0.02939
	Carpet & Combined materials	11	5.5	2.445048	0.014489
	mixing exhausts&combined materials	11	31	0.177822	0.858864

Friedman ANOVA and Kendall Coeff. of Concordance (exp2.sta)					
ANOVA Chi Sqr. (N = 5, df = 6) = 6.863309 p < .33370					
Coeff. of Concordance = .22878 Aver. rank r = .03597					
		Average Rank	Sum of Ranks	Mean	Std.Dev.
4hrs	Mixing room	3.6	18	-0.19	0.181
8hrs	Mixing room	4.8	24	-0.02	0.455
24hrs	Mixing room	2.7	13.5	-0.425	0.443
48hrs	Mixing room	5.5	27.5	0.07	0.275
72hrs	Mixing room	3.3	16.5	-0.16	0.281
144hrs	Mixing room	4.8	24	-0.05	0.512
168hrs	Mixing room	3.3	16.5	-0.195	0.396

Friedman ANOVA and Kendall Coeff. of Concordance (exp2.sta)					
ANOVA Chi Sqr. (N = 5, df = 6) = 9.021583 p < .17241					
Coeff. of Concordance = .30072 Aver. rank r = .12590					
Time (hrs)		Average Rank	Sum of Ranks	Mean	Std.Dev.
4hrs	Carpet	4.9	24.5	-0.22	0.330
8hrs	Carpet	5	25	-0.16	0.244
24hrs	Carpet	3	15	-0.455	0.501
48hrs	Carpet	3.6	18	-0.3	0.192
72hrs	Carpet	3.1	15.5	-0.515	0.488
144hrs	Carpet	5.7	28.5	-0.13	0.289
168hrs	Carpet	2.7	13.5	-0.48	0.345

Friedman ANOVA and Kendall Coeff. of Concordance (exp2.sta)					
ANOVA Chi Sqr. (N = 5, df = 6) = 10.58696 p < .10205					
Coeff. of Concordance = .35290 Aver. rank r = .19112					
Time (hrs)		Average Rank	Sum of Ranks	Mean	Std.Dev.
4hrs	Carpet&ainted gypsum boards	3.9	19.5	-0.105	0.257633
8hrs	Carpet&ainted gypsum boards	6	30	0.175	0.256174
24hrs	Carpet&ainted gypsum boards	3	15	-0.32	0.634035
48hrs	Carpet&ainted gypsum boards	4.3	21.5	-0.1	0.27329
72hrs	Carpet&ainted gypsum boards	3.2	16	-0.305	0.455316
144hrs	Carpet&ainted gypsum boards	5.2	26	0.105	0.476445
168hrs	Carpet&ainted gypsum boards	2.4	12	-0.37	0.449096

Experiment 3

Carpet and painted gypsum board

Time		Valid N	Mean	Confid. -95.000%	Confid. +95.000%	Minimum	Maximum	Std.Dev.	Standard Error
	Room 1(empty)	18	0.443	0.263	0.623	-0.55	0.90	0.362	0.085
	Room 2(empty)	18	0.437	0.259	0.615	-0.25	1.00	0.390	0.085
	Room 3(empty)	18	0.200	-0.004	0.404	-0.55	0.90	0.449	0.098
4hrs	Painted gypsum board	19	0.050	-0.148	0.248	-0.75	0.65	0.411	0.094
	Carpet	19	-0.227	-0.368	-0.087	-0.80	0.33	0.308	0.067
	Carpet +painted gypsum board	19	-0.042	-0.264	0.180	-0.85	0.95	0.488	0.107
24hrs	Painted gypsum board	18	0.115	-0.088	0.319	-0.90	0.85	0.447	0.097
	Carpet	18	-0.369	-0.567	-0.172	-0.98	0.60	0.398	0.094
	Carpet +painted gypsum board	18	-0.014	-0.246	0.218	-0.73	0.83	0.466	0.110
48hrs	Painted gypsum board	18	0.047	-0.154	0.249	-0.68	0.95	0.419	0.096
	Carpet	18	-0.290	-0.521	-0.060	-0.88	0.85	0.464	0.109
	Carpet +painted gypsum board	18	-0.117	-0.312	0.079	-0.85	0.63	0.393	0.093
72hrs	Painted gypsum board	20	0.000	-0.215	0.215	-0.88	0.88	0.459	0.103
	Carpet	20	-0.350	-0.574	-0.126	-0.98	0.75	0.480	0.107
	Carpet +painted gypsum board	20	-0.204	-0.397	-0.010	-0.93	0.55	0.413	0.092
96hrs	Painted gypsum board	19	0.103	-0.050	0.256	-0.80	0.88	0.345	0.074
	Carpet	19	-0.343	-0.572	-0.115	-0.98	0.75	0.474	0.109
	Carpet +painted gypsum board	19	-0.130	-0.326	0.065	-0.83	0.83	0.405	0.093
168hrs	Painted gypsum board	17	-0.021	-0.201	0.158	-0.83	0.85	0.383	0.086
	Carpet	17	-0.334	-0.545	-0.123	-0.95	0.33	0.410	0.099
	Carpet +painted gypsum board	17	-0.087	-0.298	0.124	-0.75	0.48	0.411	0.100
Part2									
(carpet was taken out of rooms 2 and 3)									
172hrs	Empty room	10	0.125	-0.233	0.483	-0.83	0.83	0.501	0.158
	Painted gypsum board	10	0.002	-0.307	0.312	-0.93	0.48	0.432	0.137
192hrs	Empty room	12	0.150	-0.149	0.449	-0.60	0.85	0.471	0.136
	Painted gypsum board	12	0.023	-0.331	0.377	-0.98	0.88	0.557	0.161
216hrs	Empty room	10	0.275	-0.024	0.574	-0.53	0.98	0.417	0.132
	Painted gypsum board	10	0.073	-0.287	0.432	-0.78	0.85	0.503	0.159

Wilcoxon Matched Pairs Test (exp.3)

Time		Valid N	T	Z	p-level
4hrs	Carpet vs Carpet+painted gypsum board	21	52.5	1.9600	0.050009
24hrs	Carpet vs Carpet+painted gypsum board	18	10	3.2881	0.00101
48hrs	Carpet vs Carpet+painted gypsum board	18	37	2.1122	0.0347
72hrs	Carpet vs Carpet+painted gypsum board	20	47.5	2.1466	0.0318
96hrs	Carpet vs Carpet+painted gypsum board	19	32	2.535	0.0112
168hrs	Carpet vs Carpet+painted gypsum board	17	9	3.195	0.0014

Desorption phase for the empty room that had carpet

Friedman ANOVA and Kendall Coeff. of Concordance (exp3.sta)					
ANOVA Chi Sqr. (N = 8, df = 2) = 1.750000 p < .41687					
Coeff. of Concordance = .10938 Aver. rank r = -.0179					
		Average	Sum of		
Time		Rank	Ranks	Mean	Std.Dev.
172hrs	Empty room	2.25	18	0.184375	0.396624
192hrs	Empty room	1.625	13	0.103125	0.408052
216hrs	Empty room	2.125	17	0.25625	0.458988

Desorption phase for the room with painted gypsum board after taken out the carpet

Friedman ANOVA and Kendall Coeff. of Concordance (exp3.sta)					
ANOVA Chi Sqr. (N = 8, df = 2) = .0689655 p < .96611					
Coeff. of Concordance = .00431 Aver. rank r = -.1379					
		Average	Sum of		
Time (hrs)		Rank	Ranks	Mean	Std.Dev.
172hrs	Painted gypsum board	2.0625	16.5	-0.04688	0.470645
192hrs	Painted gypsum board	1.9375	15.5	-0.04375	0.472786
216hrs	Painted gypsum board	2	16	-0.00312	0.477613

Experiment 4 Carpet and virgin gypsum board

Time		Valid N	Mean	Confid. -95.000%	Confid. +95.000%	Minimum	Maximum	Std.Dev.	Standard Error
	Room 1	21	0.262	0.061	0.463	-0.60	0.98	0.441	0.096
	Room 2	21	0.311	0.126	0.495	-0.53	1.00	0.406	0.088
	Room 3	21	0.437	0.259	0.615	-0.25	1.00	0.390	0.085
4hrs	Virgin gypsun board	20	-0.057	-0.214	0.099	-0.70	0.50	0.334	0.075
	VGB+Carpet	20	-0.109	-0.311	0.093	-0.88	0.75	0.432	0.097
	Carpet	20	-0.239	-0.385	-0.093	-0.80	0.33	0.312	0.070
24 hrs	Virgin gypsun board	18	-0.076	-0.255	0.102	-0.68	0.70	0.359	0.085
	VGB+Carpet	18	-0.176	-0.402	0.049	-0.93	0.60	0.454	0.107
	Carpet	18	-0.369	-0.567	-0.172	-0.98	0.60	0.398	0.094
48hrs	Virgin gypsun board	18	-0.113	-0.279	0.054	-0.90	0.48	0.336	0.079
	VGB+Carpet	18	-0.204	-0.359	-0.050	-0.80	0.35	0.310	0.073
	Carpet	18	-0.279	-0.511	-0.047	-0.88	0.85	0.467	0.110
72hrs	Virgin gypsun board	20	-0.056	-0.311	0.198	-0.95	0.88	0.544	0.122
	VGB+Carpet	20	-0.274	-0.480	-0.068	-0.93	0.73	0.440	0.098
	Carpet	20	-0.350	-0.574	-0.126	-0.98	0.75	0.480	0.107
96hrs	Virgin gypsun board	19	-0.105	-0.311	0.100	-0.85	0.83	0.426	0.098
	VGB+Carpet	19	-0.239	-0.430	-0.049	-0.95	0.60	0.395	0.091
	Carpet	19	-0.343	-0.572	-0.115	-0.98	0.75	0.474	0.109
168hrs	Virgin gypsun board	17	-0.031	-0.311	0.249	-0.95	0.93	0.545	0.132
	VGB+Carpet	17	-0.299	-0.541	-0.056	-0.90	0.83	0.472	0.115
	Carpet	17	-0.334	-0.545	-0.123	-0.95	0.33	0.410	0.099

Wilcoxon Matched Pairs Test (exp.4)

Time		Valid N	T	Z	p-level
4hrs	Carpet vs Carpet+virgin gypsum board	20	68.5	1.3626	0.173005
24hrs	Carpet vs Carpet+virgin gypsum board	18	39.5	2.0033	0.045152
48hrs	Carpet vs Carpet+virgin gypsum board	18	52	1.4589	0.1446
72hrs	Carpet vs Carpet+virgin gypsum board	20	58.5	1.1759	0.2397
96hrs	Carpet vs Carpet+virgin gypsum board	19	57.5	1.509	0.1313
168hrs	Carpet vs Carpet+virgin gypsum board	17	64	0.207	0.8361

Experiment 5 Linoleum and painted gypsum board

Time		Valid N	Mean	Confid. -95.000%	Confid. +95.000%	Minimum	Maximum	Std.Dev.	Standard Error
	Empty	32	0.312	0.149	0.475	-0.63	0.95	0.452	0.080
	Empty	32	0.380	0.227	0.534	-0.45	1.00	0.425	0.075
4hrs	Linoleum	33	-0.333	-0.466	-0.199	-0.95	0.73	0.377	0.066
	Linoleum+painting gypsum board	33	-0.145	-0.283	-0.007	-0.95	0.68	0.389	0.068
24hrs	Linoleum	29	-0.498	-0.641	-0.355	-0.98	0.50	0.376	0.070
	Linoleum+painting gypsum board	29	-0.206	-0.371	-0.041	-0.93	0.80	0.434	0.081
48hrs	Linoleum	29	-0.410	-0.562	-0.258	-0.98	0.60	0.400	0.074
	Linoleum+painting gypsum board	29	-0.271	-0.409	-0.132	-0.85	0.50	0.365	0.068
72hrs	Linoleum	32	-0.391	-0.540	-0.243	-0.98	0.60	0.411	0.073
	Linoleum+painting gypsum board	32	-0.224	-0.365	-0.084	-0.95	0.65	0.390	0.069
96hrs	Linoleum	32	-0.395	-0.540	-0.250	-0.98	0.55	0.402	0.071
	Linoleum+painting gypsum board	32	-0.160	-0.305	-0.015	-0.93	0.63	0.403	0.071
168hrs	Linoleum	31	-0.339	-0.474	-0.204	-0.93	0.73	0.368	0.066
	Linoleum+painting gypsum board	31	-0.108	-0.245	0.029	-0.85	0.93	0.374	0.067
Part2									
172hrs	Empty	27	-0.117	-0.257	0.023	-0.80	0.88	0.354	0.068
	painting gypsum board	27	0.105	-0.064	0.274	-0.53	0.93	0.427	0.082
192hrs	Empty	28	0.136	-0.050	0.322	-0.75	0.95	0.480	0.091
	painting gypsum board	28	0.013	-0.139	0.166	-0.78	0.88	0.393	0.074
216hrs	Empty	29	0.125	-0.070	0.320	-0.93	0.93	0.514	0.095
	painting gypsum board	29	0.084	-0.069	0.237	-0.83	0.78	0.402	0.075
240hrs	Empty	29	0.335	0.175	0.496	-0.73	0.98	0.422	0.078
	painting gypsum board	29	0.088	-0.065	0.241	-0.68	0.93	0.401	0.075

Wilcoxon Matched Pairs Test (exp.5)

Time		Valid N	T	Z	p-level
	The two empty rooms	32	154.5	1.3623	0.1731
4hrs	Linoleum vs Linoleum+painting gypsum board	33	49	3.5068	0.00045
24hrs	Linoleum vs Linoleum+painting gypsum board	29	37.5	3.6398	0.00027
48hrs	Linoleum vs Linoleum+painting gypsum board	29	128	1.7079	0.0877
72hrs	Linoleum vs Linoleum+painting gypsum board	32	102.5	2.8513	0.0044
96hrs	Linoleum vs Linoleum+painting gypsum board	32	81.5	3.413	0.0006
168hrs	Linoleum vs Linoleum+painting gypsum board	31	64	3.466	0.0005

Desorption phase for the empty room that had linoleum

Friedman ANOVA and Kendall Coeff. of Concordance (exp.5)					
ANOVA Chi Sqr. (N = 25, df = 4) = 34.79184 p < .00000					
Coeff. of Concordance = .34792 Aver. rank r = .32075					
Time (hrs)		Average Rank	Sum of Ranks	Mean	Std.Dev.
168hrs	Linoleum	1.7	42.5	-0.353	0.36907
172hrs	Empty	2.56	64	-0.126	0.36575
192hrs	Empty	3.58	89.5	0.148	0.45922
216hrs	Empty	3.44	86	0.091	0.53189
240hrs	Empty	4.06	101.5	0.317	0.43408

Friedman ANOVA and Kendall Coeff. of Concordance (exp.5)					
ANOVA Chi Sqr. (N = 26, df = 3) = 18.82470 p < .00030					
Coeff. of Concordance = .24134 Aver. rank r = .21100					
Time (hrs)		Average Rank	Sum of Ranks	Mean	Std.Dev.
172hrs	Empty	1.69231	44	-0.124	0.3585
192hrs	Empty	2.51923	65.5	0.17692	0.47349
216hrs	Empty	2.57692	67	0.10192	0.52411
240hrs	Empty	3.21154	83.5	0.34038	0.44171

Desorption phase for the room with painted gypsum board after taken out the linoleum

Friedman ANOVA and Kendall Coeff. of Concordance (exp.5)					
ANOVA Chi Sqr. (N = 25, df = 4) = 4.782077 p < .31042					
Coeff. of Concordance = .04782 Aver. rank r = .00815					
Time (hrs)		Average Rank	Sum of Ranks	Mean	Std.Dev.
168hrs	Linoleum +painted gypsum board	2.44	61	-0.104	0.371
172hrs	Painted gypsum board	3.34	83.5	0.11	0.443
192hrs	Painted gypsum board	3	75	0.018	0.412
216hrs	Painted gypsum board	3.02	75.5	0.052	0.410
240hrs	Painted gypsum board	3.2	80	0.063	0.425

Experiment 6 Linoleum and Semia

Time		Valid N	Mean	Confid. -95.000%	Confid. +95.000%	Minimum	Maximum	Std.Dev.	Standard Error
	Empty	32	0.381	0.239	0.524	-0.48	0.98	0.395	0.070
	Empty	32	0.352	0.215	0.490	-0.45	0.95	0.382	0.068
4hrs	Linoleum	33	0.355	0.197	0.512	-0.63	0.98	0.445	0.078
	Linoleum+Semia	33	0.321	0.166	0.476	-0.80	0.98	0.437	0.076
24hrs	Linoleum	29	0.383	0.219	0.546	-0.68	0.95	0.430	0.080
	Linoleum+Semia	29	0.170	-0.009	0.348	-0.58	0.95	0.469	0.087
48hrs	Linoleum	29	0.343	0.164	0.522	-0.50	0.95	0.471	0.088
	Linoleum+Semia	29	0.180	0.023	0.337	-0.70	0.85	0.413	0.077
72hrs	Linoleum	32	0.423	0.268	0.579	-0.78	0.93	0.432	0.076
	Linoleum+Semia	32	0.162	0.006	0.317	-0.83	0.83	0.431	0.076
96hrs	Linoleum	32	0.423	0.264	0.581	-0.78	0.98	0.439	0.078
	Linoleum+Semia	32	0.184	0.031	0.337	-0.95	0.98	0.424	0.075
168hrs	Linoleum	31	0.322	0.137	0.506	-0.95	0.95	0.503	0.090
	Linoleum+Semia	31	0.130	-0.061	0.320	-0.93	0.93	0.520	0.093
Part2									
172hrs	Empty	27	0.373	0.160	0.586	-0.85	0.93	0.539	0.104
	Semia	27	0.208	0.006	0.410	-0.85	0.98	0.511	0.098
192hrs	Empty	28	0.329	0.149	0.510	-0.80	0.93	0.466	0.088
	Semia	28	0.243	0.054	0.432	-0.93	0.93	0.487	0.092
216hrs	Empty	29	0.313	0.146	0.480	-0.93	0.98	0.440	0.082
	Semia	29	0.336	0.170	0.502	-0.95	0.98	0.436	0.081
240hrs	Empty	29	0.317	0.127	0.508	-0.78	0.95	0.501	0.093
	Semia	29	0.288	0.129	0.446	-0.53	0.90	0.417	0.077

Wilcoxon Matched Pairs Test (exp.6)

Time		Valid N	T	Z	p-level
	The two empty rooms	32	198	0.7096	0.4780
4hrs	Linoleum vs Linoleum+Semia	33	3	4.9583	7.14678E-07
24hrs	Linoleum vs Linoleum+Semia	29	8	4.5301	5.91796E-06
48hrs	Linoleum vs Linoleum+Semia	29	11	4.3721	0.00001
72hrs	Linoleum vs Linoleum+Semia	32	24.5	4.2782	0.00002
96hrs	Linoleum vs Linoleum+Semia	32	22.5	4.419	0.00001
168hrs	Linoleum vs Linoleum+Semia	31	46	3.836	0.0001

Desorption phase for the room with Semia after taken out the linoleum

Friedman ANOVA and Kendall Coeff. of Concordance (exp.6)					
ANOVA Chi Sqr. (N = 25, df = 4) = 2.354379 p < .67089					
Coeff. of Concordance = .02354 Aver. rank r = -.0171					
Time (hrs)		Average Rank	Sum of Ranks	Mean	Std.Dev.
168hrs	Linoleum +Semia	2.8	70	0.109	0.519
172hrs	Semia	3.08	77	0.194	0.501
192hrs	Semia	2.74	68.5	0.202	0.470
216hrs	Semia	3.34	83.5	0.323	0.440
240hrs	Semia	3.04	76	0.246	0.426

Experiment 7

Carpet and painted gypsum board

Time		Valid N	Mean	Confid. -95.000%	Confid. +95.000%	Minimum	Maximum	Std.Dev.	Standard Error
	Room 1(empty)	30	0.268	0.145	0.390	-0.50	0.93	0.328	0.060
	Room 2(empty)	30	0.252	0.133	0.370	-0.25	0.90	0.317	0.058
	Room 3(empty)	30	0.273	0.144	0.401	-0.28	0.88	0.343	0.063
	Room 4(empty)	30	0.316	0.177	0.455	-0.50	0.93	0.373	0.068
4 hrs	Carpet	33	-0.025	-0.206	0.156	-0.75	0.88	0.511	0.089
	Mixing exhausts	33	0.059	-0.085	0.203	-0.83	0.93	0.405	0.071
	Painted gypsum board	33	0.024	-0.115	0.163	-0.83	0.93	0.391	0.068
	Carpet+painting gypsum board	33	0.015	-0.146	0.177	-0.85	0.93	0.456	0.079
8hrs	Carpet	30	-0.097	-0.261	0.066	-0.88	0.83	0.437	0.080
	Mixing exhausts	30	-0.042	-0.169	0.086	-0.63	0.63	0.341	0.062
	Painted gypsum board	30	-0.032	-0.162	0.098	-0.78	0.63	0.349	0.064
	Carpet+painting gypsum board	30	-0.022	-0.178	0.133	-0.75	0.90	0.415	0.076
24hrs	Carpet	35	-0.123	-0.257	0.011	-0.85	0.55	0.389	0.066
	Mixing exhausts	35	0.011	-0.163	0.184	-1.00	0.83	0.505	0.085
	Painted gypsum board	35	0.064	-0.084	0.212	-0.90	0.90	0.431	0.073
	Carpet+painting gypsum board	35	0.194	0.044	0.343	-0.73	1.00	0.434	0.073
48hrs	Carpet	35	-0.121	-0.256	0.013	-0.83	0.83	0.391	0.066
	Mixing exhausts	35	0.014	-0.126	0.154	-0.75	0.88	0.408	0.069
	Painted gypsum board	35	0.058	-0.083	0.199	-0.75	0.80	0.411	0.070
	Carpet+painting gypsum board	35	0.118	-0.018	0.253	-0.50	0.95	0.395	0.067
72hrs	Carpet	33	-0.090	-0.254	0.074	-0.93	0.93	0.462	0.080
	Mixing exhausts	33	0.040	-0.115	0.195	-0.73	0.90	0.437	0.076
	Painted gypsum board	33	0.160	0.014	0.305	-0.63	0.93	0.410	0.071
	Carpet+painting gypsum board	33	0.222	0.105	0.339	-0.35	0.93	0.329	0.057
144hrs	Carpet	35	-0.114	-0.271	0.043	-0.85	0.83	0.457	0.077
	Mixing exhausts	35	0.019	-0.158	0.197	-0.88	0.95	0.517	0.087
	Painted gypsum board	35	0.052	-0.093	0.197	-0.95	0.95	0.422	0.071
	Carpet+painting gypsum board	35	0.155	0.000	0.310	-0.70	0.98	0.453	0.077

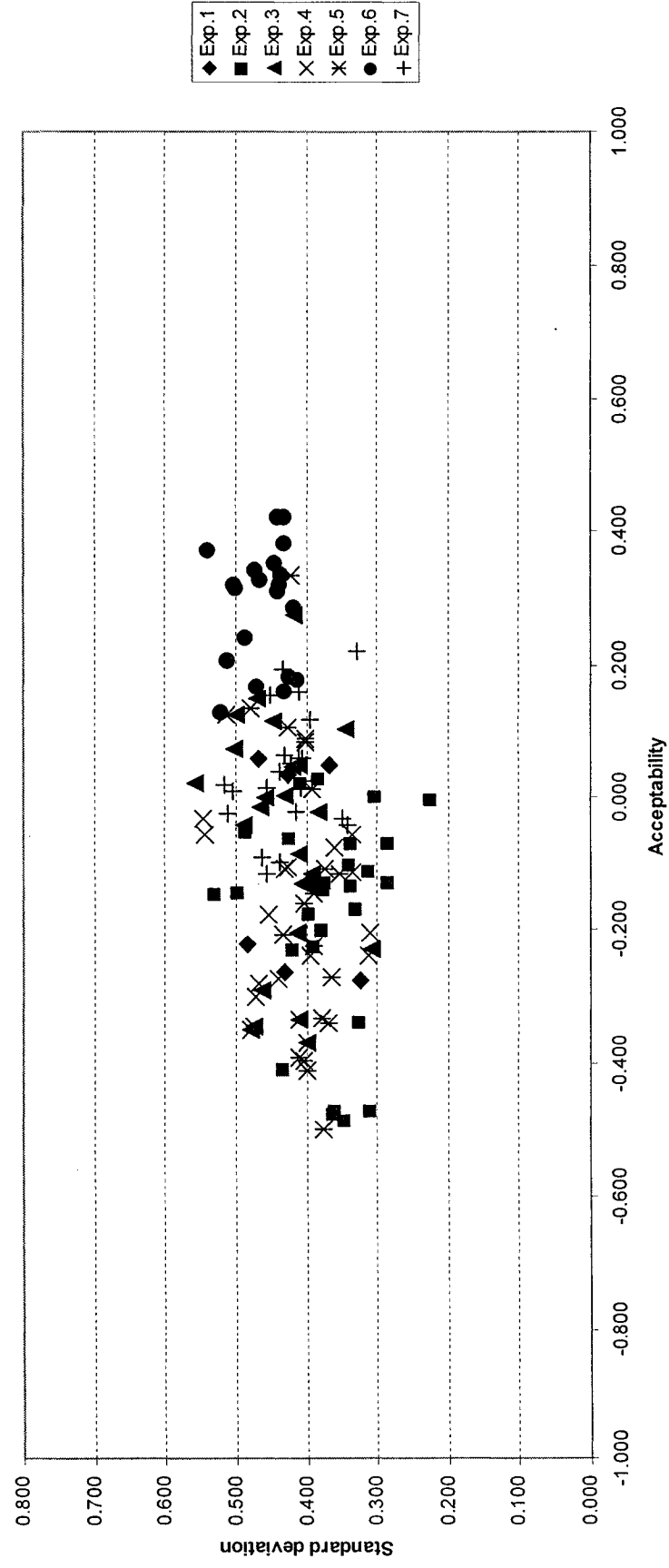
Friedman test to compare the empty rooms

Friedman ANOVA and Kendall Coeff. of Concordance (exp.7)				
ANOVA Chi Sqr. (N = 30, df = 3) = 1.070671 p < .78416				
Coeff. of Concordance = .01190 Aver. rank r = -.0222				
	Average Rank	Sum of Ranks	Mean	Std.Dev.
Room1	2.483	74.5	0.2675	0.327685
Room2	2.333	70	0.251667	0.317448
Room3	2.517	75.5	0.2725	0.343433
Room4	2.667	80	0.315833	0.372924

Wilcoxon Matched Pairs Test (exp.7)

Time	Compared rooms	Valid N	T	Z	p-level
4 hrs	Carpet & mixing exhausts	33	208	1.2954	0.1952
	Carpet & Combined materials	33	217	0.8789	0.3795
	mixing exhausts&combined materials	33	253.5	0.4824	0.6295
8hrs	Carpet & mixing exhausts	30	204	0.5862	0.5577
	Carpet & Combined materials	30	162	0.9336	0.3505
	mixing exhausts&combined materials	30	232	0.0103	0.9918
24hrs	Carpet & mixing exhausts	35	167	2.0280	0.0426
	Carpet & Combined materials	35	80	3.8491	0.0001
	mixing exhausts&combined materials	35	193.5	1.7780	0.0754
48hrs	Carpet & mixing exhausts	35	147	2.5730	0.0101
	Carpet & Combined materials	35	122	3.1612	0.0016
	mixing exhausts&combined materials	35	197.5	1.7097	0.0873
72hrs	Carpet & mixing exhausts	33	149.5	1.707	0.0878
	Carpet & Combined materials	33	55.5	4.020	0.00006
	mixing exhausts&combined materials	33	131.5	2.478	0.0132
144hrs	Carpet & mixing exhausts	35	216.5	1.613	0.1067
	Carpet & Combined materials	35	64	3.992	0.0001
	mixing exhausts&combined materials	35	177.5	2.2521	0.0243

The experimental standard deviation as a function of the mean acceptability
vote for all performed experiments



Appendix B

Least square method

1. Sorption parameters for the room surfaces:

1.1 when linoleum was the pollution source

Time (hrs)	Perceived concentration (decipol)	Perceived concentration- the test room background (decipol)	Trapezoid area
0	19.100	18.300	16.711
1	15.922	15.122	13.797
2	13.272	12.472	11.368
3	11.064	10.264	9.343
4	9.223	8.423	16.283
6	8.660	7.860	15.106
8	8.046	7.246	13.921
10	7.475	6.675	12.819
12	6.944	6.144	11.796
14	6.452	5.652	10.846
16	5.994	5.194	9.963
18	5.569	4.769	9.142
20	5.173	4.373	8.380
22	4.806	4.006	7.672
24	4.465	3.665	7.014
26	4.148	3.348	6.403
28	3.854	3.054	5.835
30	3.581	2.781	5.307
32	3.327	2.527	4.817
34	3.091	2.291	4.362
36	2.871	2.071	3.939
38	2.668	1.868	3.546
40	2.478	1.678	3.181
42	2.302	1.502	2.841
44	2.139	1.339	2.526
46	1.987	1.187	2.233
48	1.846	1.046	1.961
50	1.715	0.915	1.709
52	1.594	0.794	1.474
54	1.480	0.680	1.256
56	1.375	0.575	1.053
58	1.278	0.478	0.865
60	1.187	0.387	0.690
62	1.103	0.303	0.528
64	1.025	0.225	0.377
66	0.952	0.152	0.236
68	0.884	0.084	0.106
70	0.822	0.022	
72	0.763		

Total area= 229.4

$Me = ((Ac * Q) - Ce * V) / A$
 $Ac = 229.43 \text{ decipol} * \text{hour}$
 $Q = 32 \text{ m}^3/\text{h}$
 $Ce = 19.1 \text{ decipol}$
 $V = 40 \text{ m}^3 \text{ and } A = 90 \text{ m}^2$
 $Me = 73.08$
 $Ke = Me / Ce = 3.8 \text{ m}$

Matlab 6.5:

```

function C=CVAL22(k,t)
ka=k;%(1);
kd=ka/3.8;%k(2);
N=.8;
L=2.25;
Ce=19.1;
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2);

```

```

function Err=errortotal(k)
DataB =[ 0  19.1000
         4.0000  9.2000
        24.0000  2.5000
        48.0000  2.5000
        72.0000  0.8000];
mm=max(size(DataB));
for i=1:mm
    Erri(i)=CVAL22(k,DataB(i,1))-DataB(i,2);
end
Err=norm(Erri)^2;

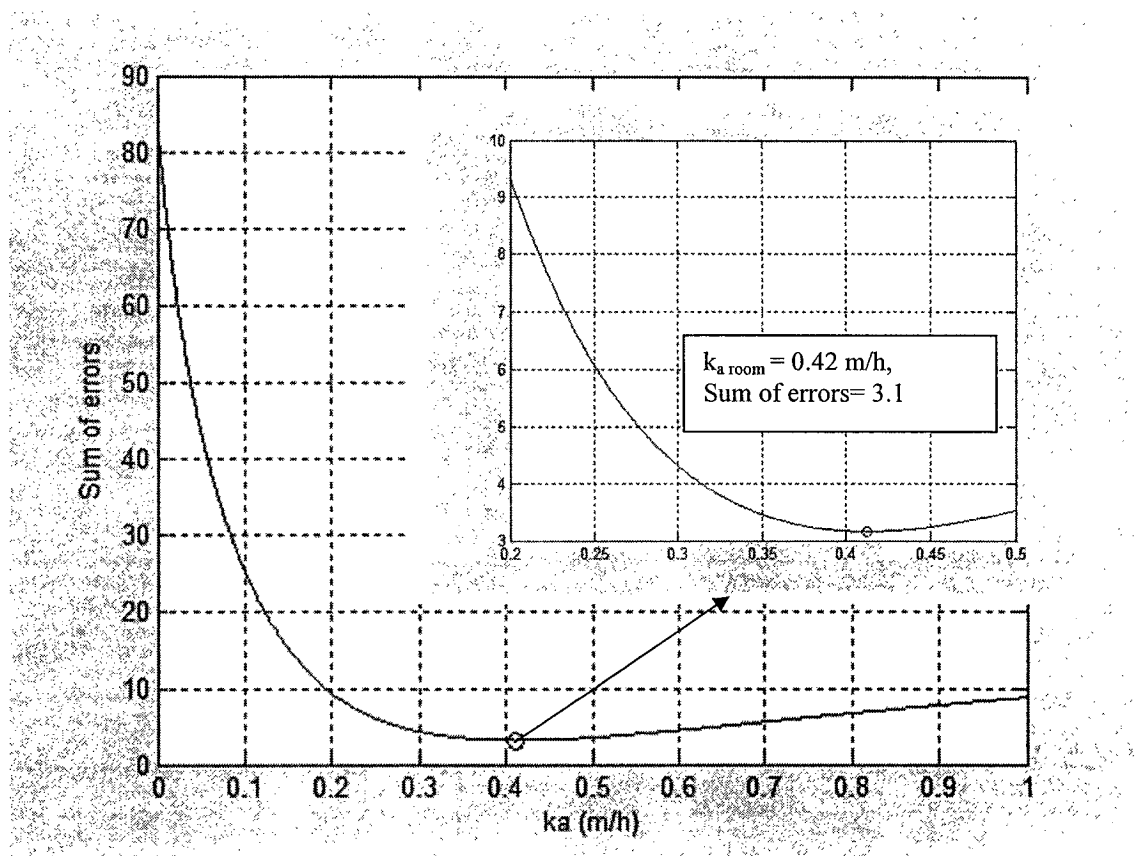
```

```

clear
clc
k=0.0:.001:2.0;
m=length(k)
for km=1:m
    yaxis(km)=errortotal(k(km));
end

plot(k,yaxis),grid
hold on
kamin=fmin('errortotal',0,5)
plot(kamin,errortotal(kamin),'o')

```

1.2 when carpet was the pollution source

Time (hrs)	Perceived concentration (decipol)	Perceived concentration- the test room background (decipol)	Trapezoid area
0	18.700	18.200	14.504
1	11.307	10.807	8.572
2	6.837	6.337	4.985
3	4.134	3.634	2.817
4	2.500	2.000	4.147
6	2.648	2.148	4.192
8	2.545	2.045	3.990
10	2.445	1.945	3.795
12	2.350	1.850	3.608
14	2.258	1.758	3.428
16	2.170	1.670	3.255
18	2.085	1.585	3.089

20	2.004	1.504	2.930
22	1.926	1.426	2.777
24	1.851	1.351	2.629
26	1.778	1.278	2.488
28	1.709	1.209	2.352
30	1.642	1.142	2.221
32	1.578	1.078	2.095
34	1.517	1.017	1.974
36	1.458	0.958	1.858
38	1.401	0.901	1.747
40	1.346	0.846	1.640
42	1.294	0.794	1.537
44	1.243	0.743	1.438
46	1.195	0.695	1.342
48	1.148	0.648	1.251
50	1.103	0.603	1.163
52	1.060	0.560	1.079
54	1.019	0.519	0.998
56	0.979	0.479	0.920
58	0.941	0.441	0.845
60	0.904	0.404	0.773
62	0.869	0.369	0.704
64	0.835	0.335	0.637
66	0.802	0.302	0.573
68	0.771	0.271	0.512
70	0.741	0.241	0.453
72	0.712	0.212	0.396
74	0.684	0.184	0.342
76	0.658	0.158	0.289
78	0.632	0.132	0.239
80	0.607	0.107	0.191
82	0.584	0.084	0.144
84	0.561	0.061	0.100
86	0.539	0.039	0.057
88	0.518	0.018	

Total area = 101.08

Q=32 m³/h
Ce=18.7 decipol
V=40 m³ and A=90 m²
Me= 27.63
Ke= 1.477

Matlab.6.5:

function C=CVAL22(k,t)

```

ka=k;%(1);
kd=ka/1.48;%k(2);
N=.8;
L=2.25;
Ce=18.7;
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2);

```

```

function Err=errortotal(k)
DataB =[ 0   18.7000
         4.0000  2.5000
        24.0000  2.2000
        48.0    1.1000];

mm=max(size(DataB));
for i=1:mm
    Erri(i)=CVAL22(k,DataB(i,1))-DataB(i,2);
end
Err=norm(Erri)^2;

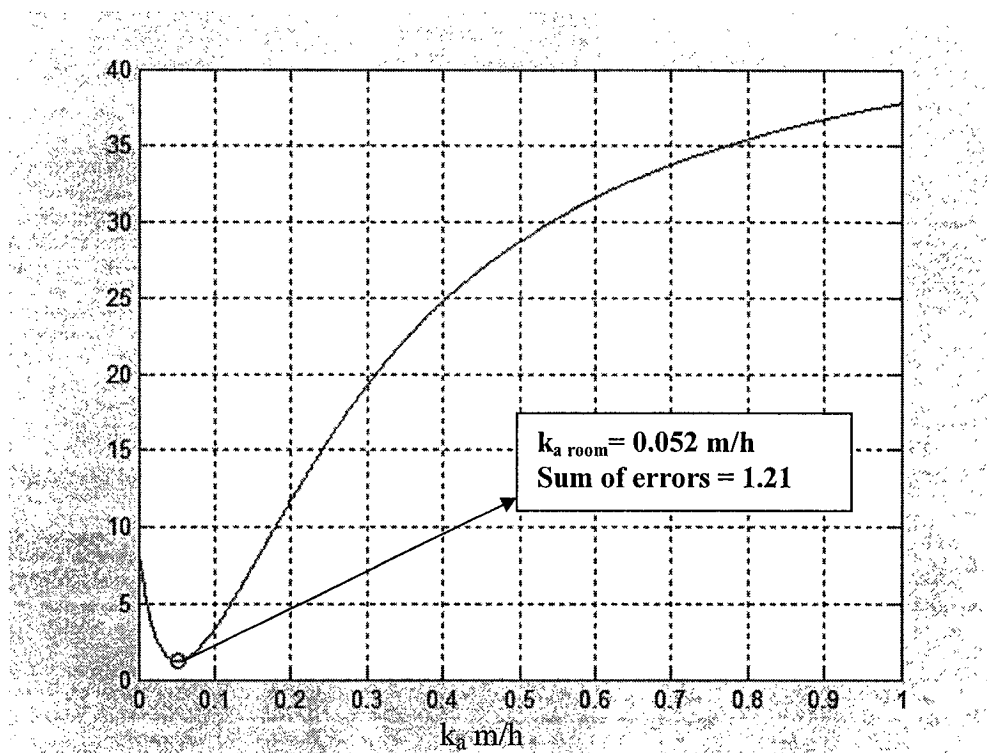
```

```

clear
clc
k=0.0:.001:1.0;
m=length(k)
for km=1:m
    yaxis(km)=errortotal(k(km));
end

plot(k,yaxis),grid
hold on
kamin=fmin('errortotal',0,5)
plot(kamin,errortotal(kamin),'o')

```



2. Sorption parameters for painted gypsum board

2.1. when linoleum was the pollution source and sorption on room surfaces was neglected

Time (hrs)	Perceived concentration (decipol)	Trapezoid area
0	4.588	8.71
2	4.123	7.83
4	3.705	7.04
6	3.330	6.32
8	2.993	5.68
10	2.690	5.11
12	2.417	4.59
14	2.172	4.12
16	1.952	3.71
18	1.755	3.33
20	1.577	2.99
22	1.417	2.69
24	1.274	2.42
26	1.145	2.17
28	1.029	1.95
30	0.924	1.76
32	0.831	1.58
34	0.747	1.42

36	0.671	1.27
38	0.603	1.14
40	0.542	1.03
42	0.487	0.92
44	0.438	0.83
46	0.393	0.75
48	0.354	0.67
50	0.318	0.60
52	0.286	0.54
54	0.257	0.49
56	0.231	0.44
58	0.207	0.39
60	0.186	0.35
62	0.167	0.32
64	0.150	0.29
66	0.135	0.26
68	0.122	0.23
70	0.109	0.21
72	0.098	0.10

Total area = 83.72

$Me = ((Ac \cdot Q) - Ce \cdot V) / A$
 $Q = 32 \text{ m}^3/\text{h}$
 $Ce = 8.8 - 3 = 5.8 \text{ decipol}$
 $V = 40 \text{ m}^3$ and $A = 90 \text{ m}^2$
 $Me = 106.4$
 $Ke = 18.34 \text{ m}$

Matlab 6.5

```

function C=CVAL22(k,t)
ka=k;%(1);
kd=ka/18.34;%k(2);
N=.8;
L=0.575;
Ce=5.8;
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=(Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2));

```

```

function Err=errortotal(k)
DataB =[ 0  5.8000
         4.0000  2.4000

```

```

24.0000  1.8000
48.0000  0.3000
72.0000  0.1000]

```

```

mm=max(size(DataB));
for i=1:mm
    Erri(i)=CVAL22(k,DataB(i,1))-DataB(i,2);
end
Err=norm(Erri)^2;

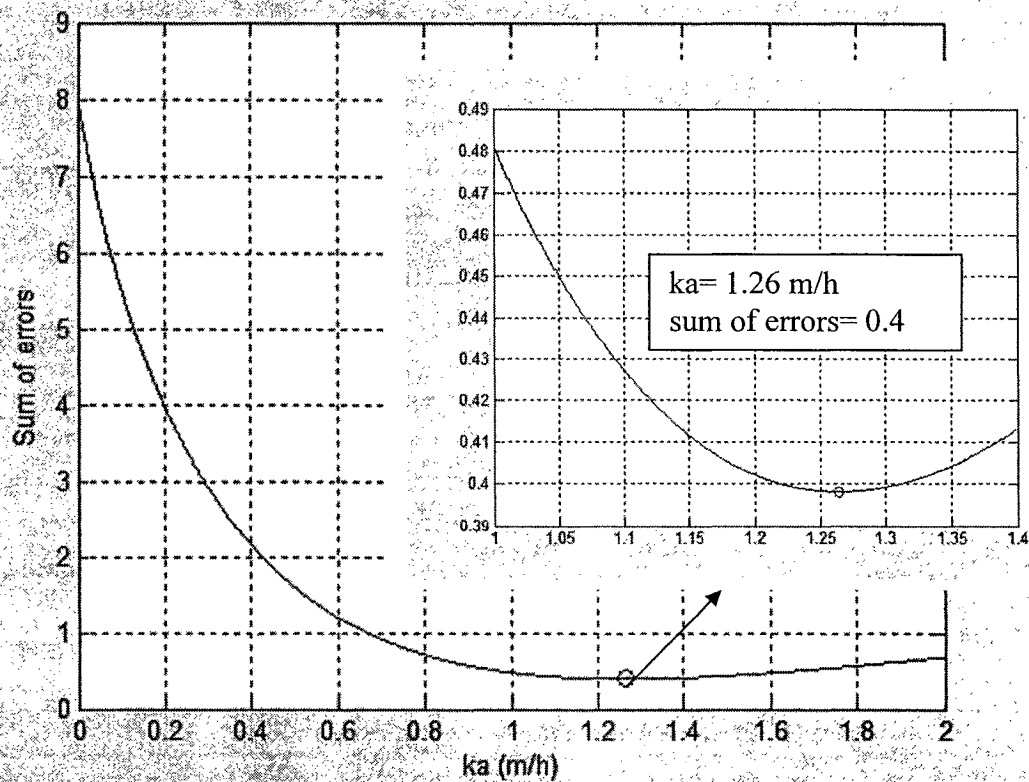
```

```

clear
clc
k=0.0:.001:2.0;
m=length(k)
for km=1:m
    yaxis(km)=errortotal(k(km));
end

plot(k,yaxis),grid
hold on
kamin=fmin('errortotal',0,5)
plot(kamin,errortotal(kamin),'o')

```



2.2. when carpet was the pollution source and and sorption on room surfaces was neglected

Time (hrs)	Perceived concentration (decipol)	Trapezoid area
0	3.743	7.191
2	3.447	6.622
4	3.175	6.098
6	2.924	5.616
8	2.692	5.172
10	2.479	4.763
12	2.283	4.386
14	2.103	4.039
16	1.936	3.720
18	1.783	3.425
20	1.642	3.154
22	1.512	2.905
24	1.393	2.675
26	1.282	2.464
28	1.181	2.269
30	1.088	2.089
32	1.002	1.924
34	0.922	1.772
36	0.849	1.632
38	0.782	1.503
40	0.720	1.384
42	0.663	1.274
44	0.611	1.173
46	0.563	1.081
48	0.518	0.995
50	0.477	0.916
52	0.439	0.844
54	0.405	0.777
56	0.373	0.716
58	0.343	0.659
60	0.316	0.607
62	0.291	0.559
64	0.268	0.515
66	0.247	0.474
68	0.227	0.437
70	0.209	0.402
72	0.193	0.370
74	0.177	0.341
76	0.163	0.314
78	0.151	0.289
80	0.139	0.266
82	0.128	0.245

84	0.118	0.226
86	0.108	0.208
88	0.100	0.192
90	0.092	0.176
92	0.085	0.162
94	0.078	0.150
96	0.072	0.138
98	0.066	0.127
100	0.061	0.061

Total area = 89.49

$Me = ((Ac \cdot Q) - Ce \cdot V) / A$
 $Ac = 89.49 \text{ decipol} \cdot \text{hour}$
 $Q = 32 \text{ m}^3/\text{h}$
 $Ce = 8.1 - 3 = 5.1 \text{ decipol}$
 $V = 40 \text{ m}^3$ and $A = 23 \text{ m}^2$

$Me = 115.64$
 $Ke = 22.68 \text{ m}$

Matlab 6.5

```

unction C=CVAL22(k,t)
ka=k;%(1);
kd=ka/22.68;%k(2);
N=.8;
L=0.575;
Ce=5.1;
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=(Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2));

```

```

function Err=errortotal(k)
DataB =[ 0   5.1000
         4.0000  2.1000
        24.0000  1.6000
        48.0000  0.5000]

mm=max(size(DataB));
for i=1:mm
    Erri(i)=CVAL22(k,DataB(i,1))-DataB(i,2);
end

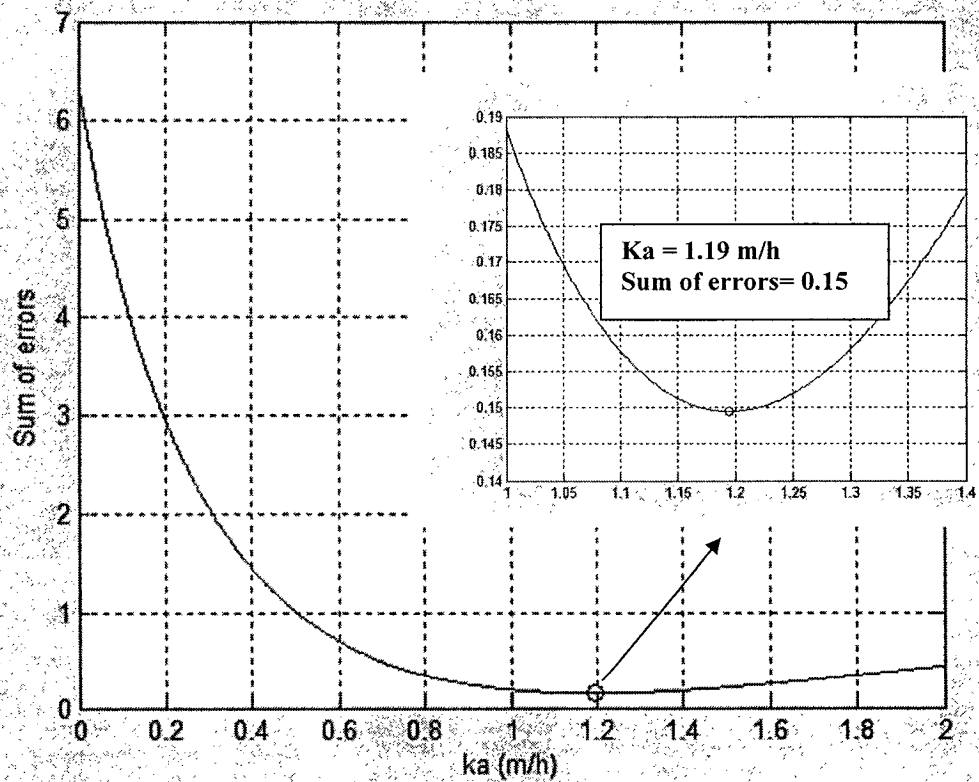
```



```
Err=norm(Erri)^2;
```

```
clear
clc
k=0.0:0.001:2.0;
m=length(k)
for km=1:m
    yaxis(km)=errortotal(k(km));
end

plot(k,yaxis),grid
hold on
kamin=fmin('errortotal',0,5)
plot(kamin,errortotal(kamin),'o')
```



3. Sorption parameters for Semia when linoleum was used as pollution source:

Time (hrs)	Perceived concentration (decipol)	Perceived concentration- the test room background (decipol)	Trapezoid area
0	1.949	1.2490	2.441
2	1.892	1.1922	2.329
4	1.837	1.1370	2.220
6	1.783	1.0834	2.115
8	1.731	1.0314	2.012
10	1.681	0.9809	1.913
12	1.632	0.9319	1.816
14	1.584	0.8843	1.722
16	1.538	0.8381	1.631
18	1.493	0.7932	1.543
20	1.450	0.7496	1.457
22	1.407	0.7074	1.374
24	1.366	0.6663	1.293
26	1.326	0.6265	1.214
28	1.288	0.5878	1.138
30	1.250	0.5502	1.064
32	1.214	0.5138	0.992
34	1.178	0.4784	0.922
36	1.144	0.4440	0.855
38	1.111	0.4106	0.789
40	1.078	0.3782	0.725
42	1.047	0.3468	0.663
44	1.016	0.3162	0.603
46	0.987	0.2866	0.544
48	0.958	0.2578	0.488
50	0.930	0.2299	0.433
52	0.903	0.2028	0.379
54	0.876	0.1764	0.327
56	0.851	0.1509	0.277
58	0.826	0.1261	0.228
60	0.802	0.1020	0.181
62	0.779	0.0786	0.134
64	0.756	0.0559	0.090
66	0.734	0.0338	0.046
68	0.712	0.0124	0.004
70	0.692	-0.0084	
72	0.671	-0.0285	

Total area = 35.96

$Me = ((Ac \cdot Q) - Ce \cdot V) / A$
 $Ac = 35.96 \text{ decipol} \cdot \text{hour}$
 $Q = 32 \text{ m}^3/\text{h}$
 $Ce = 2.5 \text{ decipol}$
 $V = 40 \text{ m}^3 \text{ and } A = 24.5 \text{ m}^2$

$Me = 42.94$
 $Ke = 17.18 \text{ m}$

Matlab 6.5

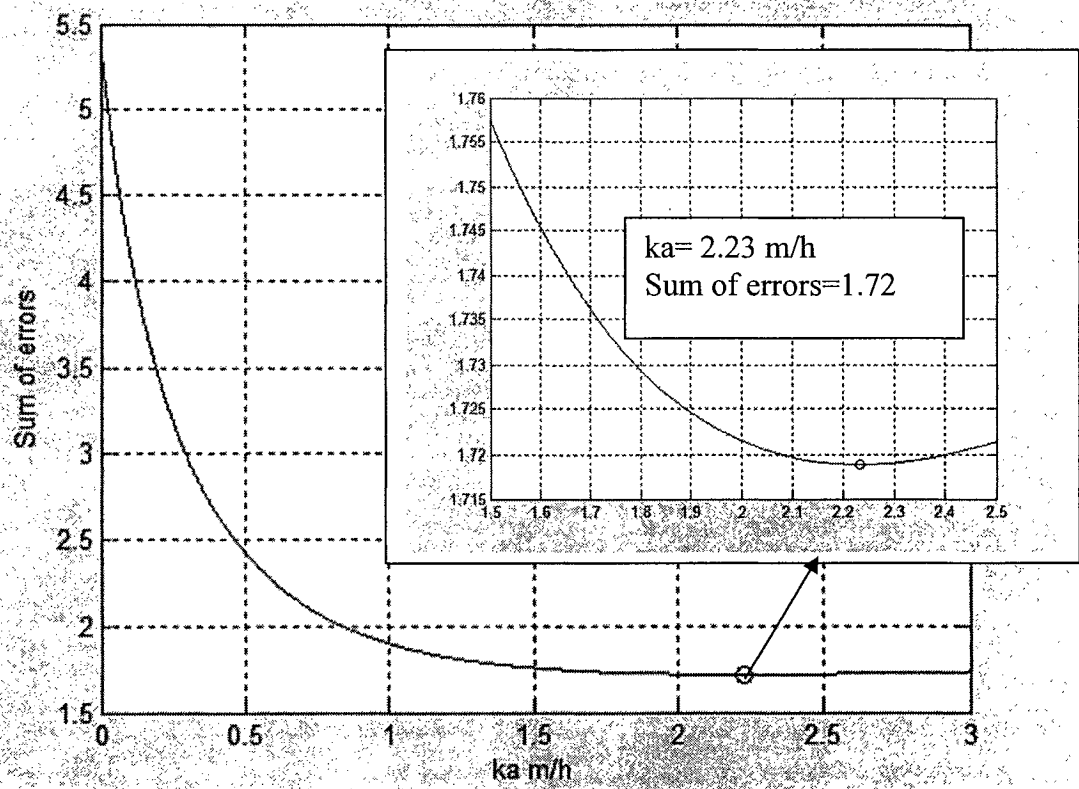
```

function C=CVAL22(k,t)
ka=k;%(1);
kd=ka/17.18;%k(2);
N=.8;
L=0.6125;
Ce=2.5;
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2);

function Err=errortotal(k)
DataB=[ 0   2.5000
        4.0000  1.6000
        24.0000  1.3000
        48.0000  0.8000
        72.0000  0.9000];
mm=max(size(DataB));
for i=1:mm
    Erri(i)=CVAL22(k,DataB(i,1))-DataB(i,2);
end
Err=norm(Erri)^2;

clear
clc
k=1.5:.001:2.5;
m=length(k)
for km=1:m
    yaxis(km)=errortotal(k(km));
end
plot(k,yaxis),grid
hold on
kamin=fmin('errortotal',0,5)
plot(kamin,errortotal(kamin),'o')

```

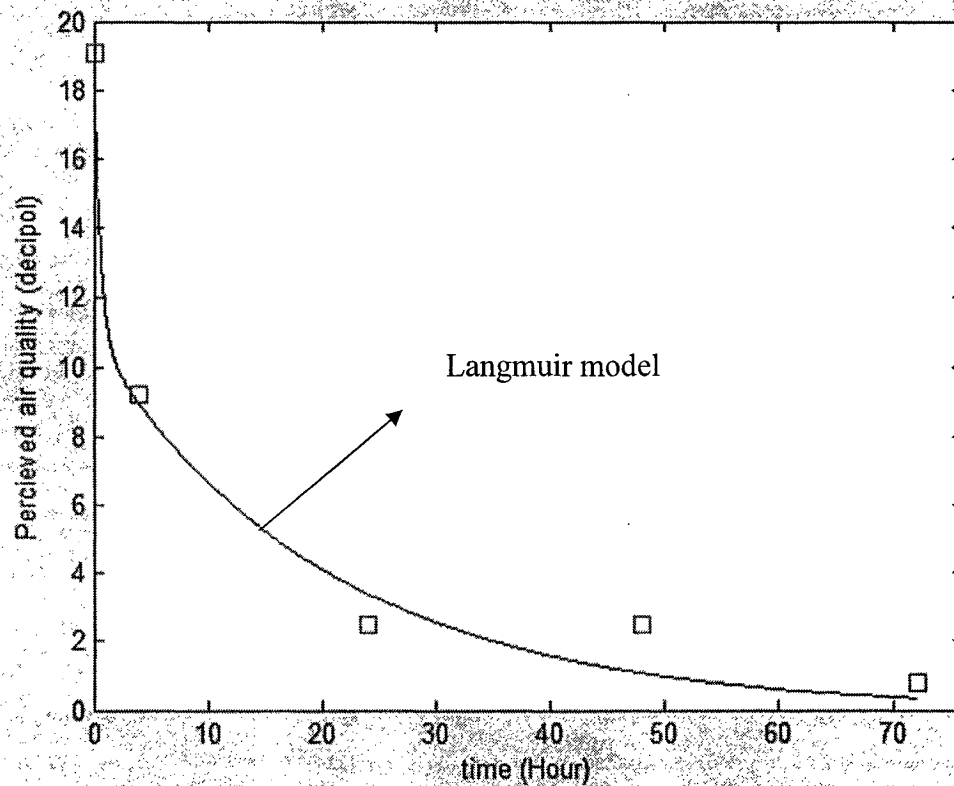


Appendix C

Best fit curve using linear Langmuir model

1. For empty room data

1.1 Desorption from room surfaces when linoleum was the pollution source during the sorption stage



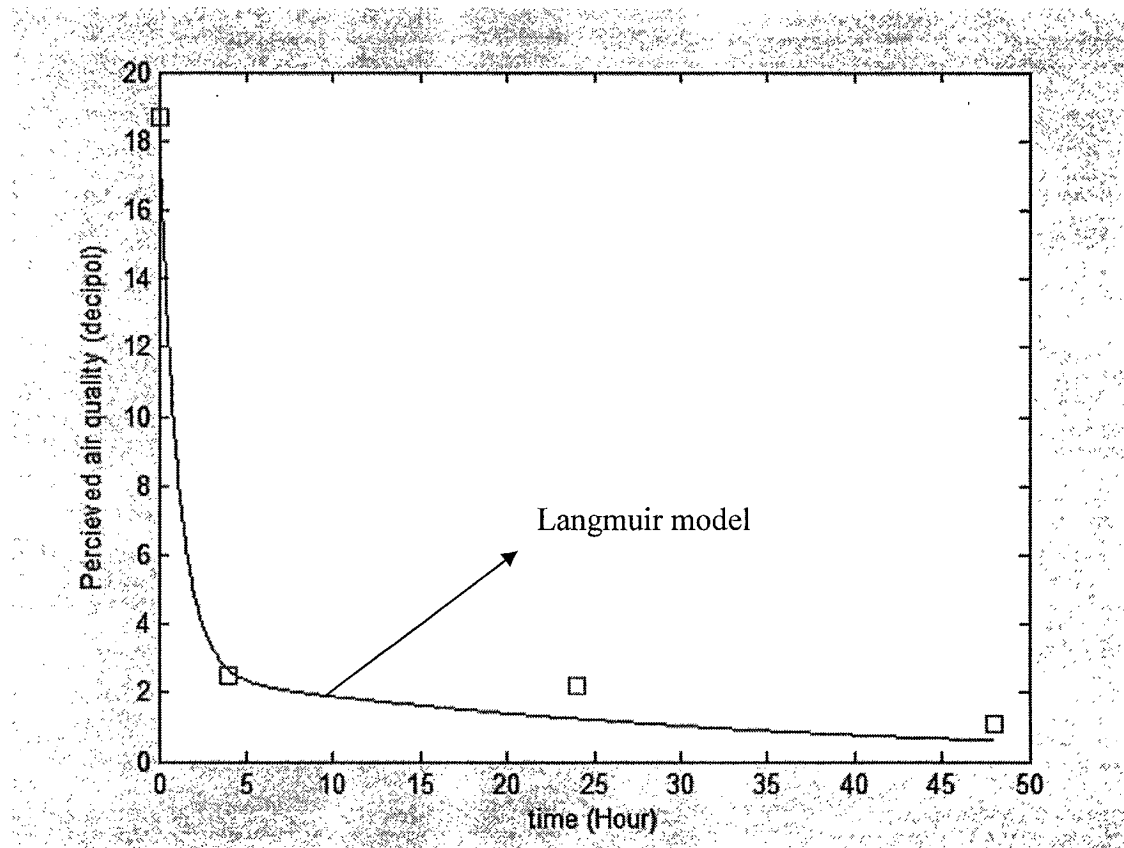
```
ka=0.41;%(1);  
kd=0.107;%k(2);  
N=.8;  
L=2.25;  
Ce=19.1;  
DATA=[0    19.1  
       4    9.2  
      24    2.5  
      48    2.5  
      72    0.8];  
b=0; yaxis=[0 20]
```

```

m=max(size(DATA));
t=0:.05:DATA(m,1);
Data=DATA-b*ones(m,1)*[0 1];
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=(Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2));
plot(t,C,Data(:,1),Data(:,2),'s')
xlabel('time (Hour)')
ylabel('Percieved air quality (decipol)')
axis([ min(t) max(t) yaxis ])

```

1.2 Desorption from room surfaces when carpet was the pollution source during the sorption stage



```

ka=0.052;%(1);
kd=0.035;%k(2);
N=8;
L=2.25;
Ce=18.7;
DATA=[0    18.7
      4     2.5

```

```

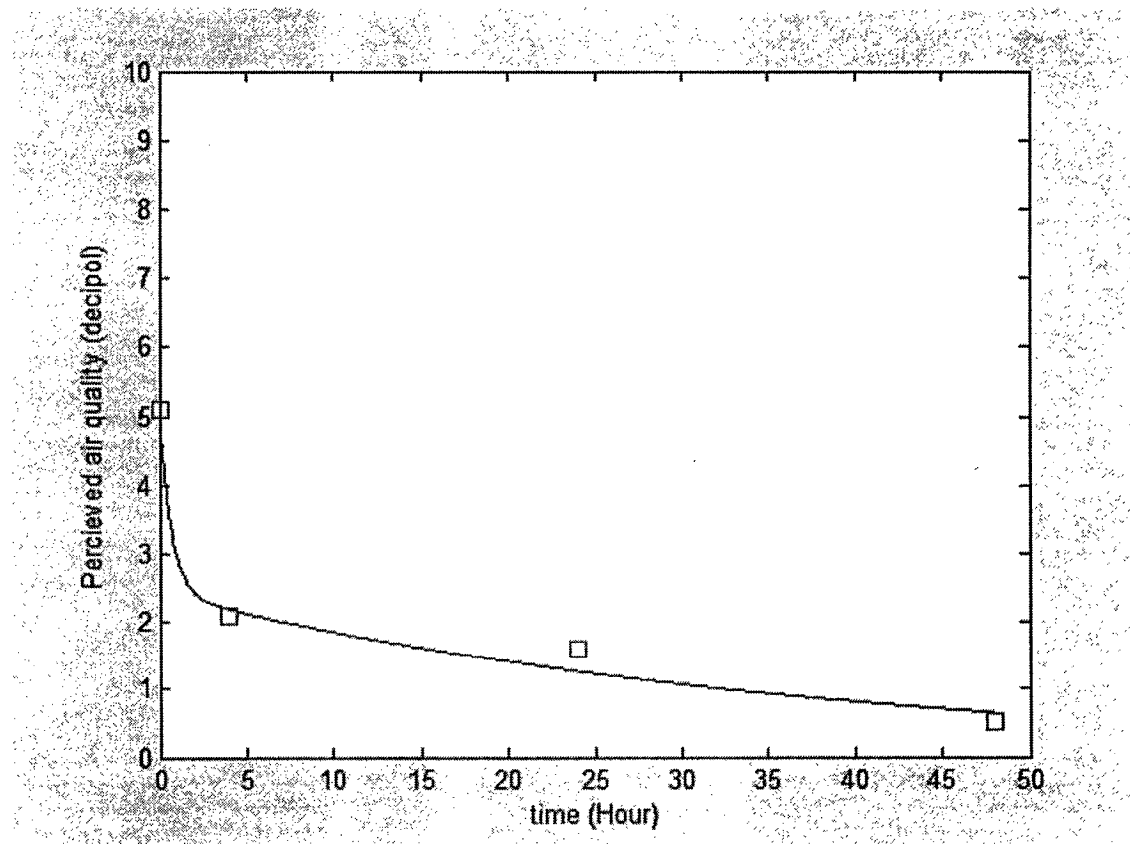
24    2.2
48    1.1];
b=0; yaxis=[0 20];

m=max(size(DATA));
t=0:.05:DATA(m,1);
Data=DATA-b*ones(m,1)*[0 1];
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=(Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2));
plot(t,C,Data(:,1),Data(:,2),'s')
xlabel('time (Hour)')
ylabel('Percieved air quality (decipol)')
axis([ min(t) max(t) yaxis ])

```

2. For painted gypsum board

2.1 Desorption data for the room with samples of painted gypsum board after the carpet was taken out of the room

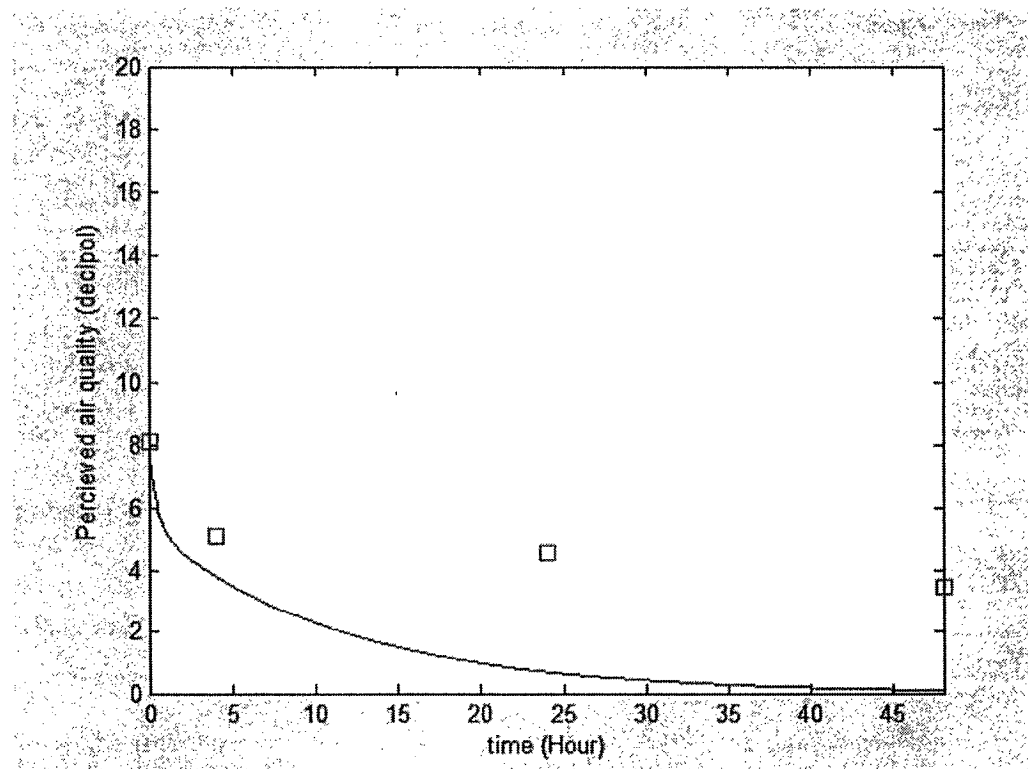


```

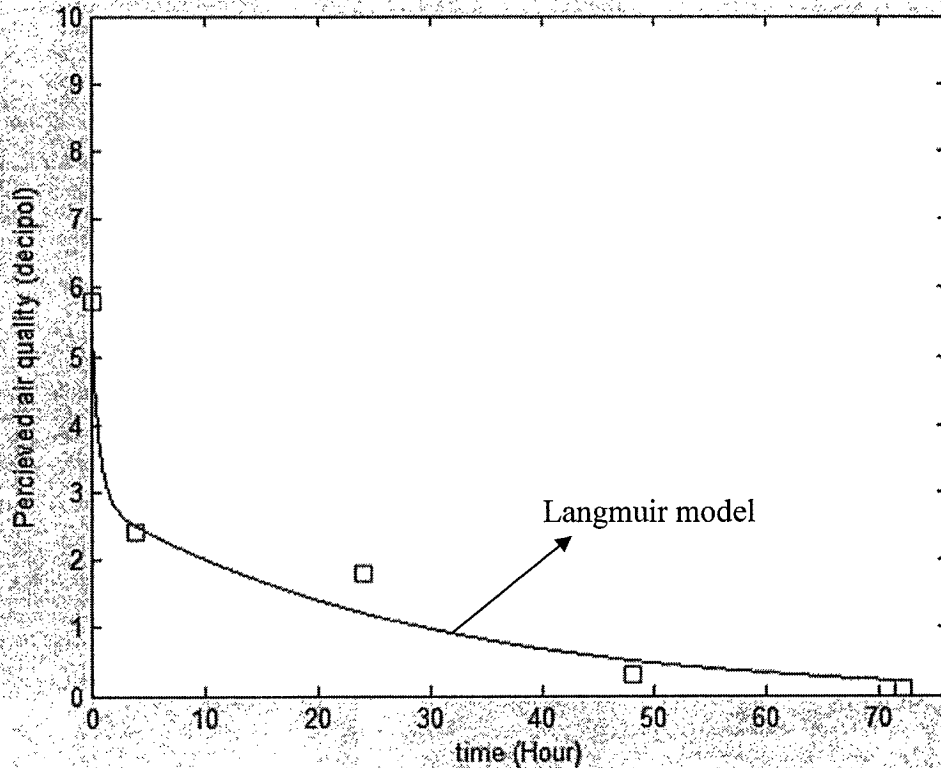
ka=1.19;%(1);
kd=0.052;%k(2);
N=.8;
L=0.575;
Ce=5.1; DATA=[0      8.1
                4      5.1
                24     4.6
                48     3.5];
b=3; yaxis=[0 10]
m=max(size(DATA));
t=0:.05:DATA(m,1);
Data=DATA-b*ones(m,1)*[0 1];
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=(Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2));
plot(t,C,Data(:,1),Data(:,2),'s')
xlabel('time (Hour)')
ylabel('Percieved air quality (decipol)')
axis([ min(t) max(t) yaxis ])

```

2.1.1 Langmuir model fit to data that include the emission from painted gypsum boards



2.2 Desorption data for the room with samples of painted gypsum board after the linoleum was taken out of the room



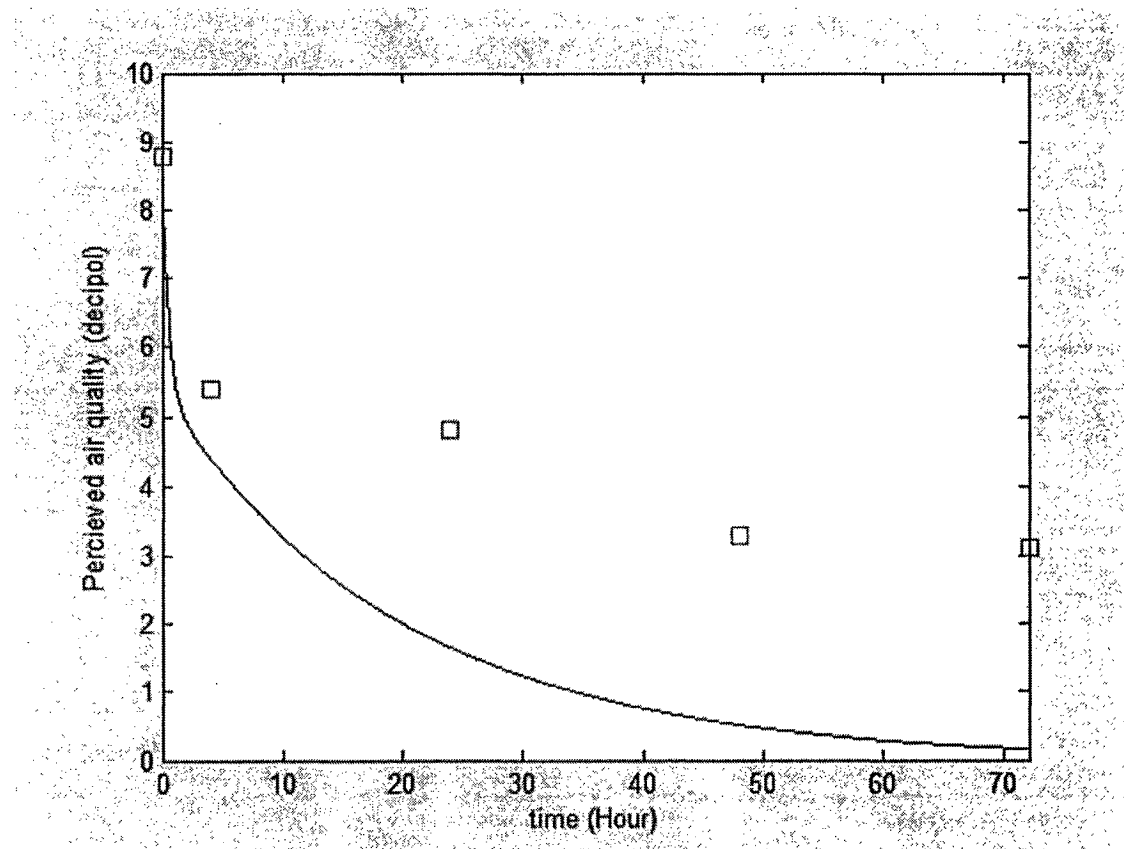
```

ka=1.26;%(1);
kd=0.07;%k(2);
N=.8;
L=0.575;
Ce=5.8;
DATA=[0 8.8
      4 5.4
      24 4.8
      48 3.3
      72 3.1]; b=3; yaxis=[0 10]
m=max(size(DATA));
t=0:.05:DATA(m,1);
Data=DATA-b*ones(m,1)*[0 1];
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=(Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2));
plot(t,C,Data(:,1),Data(:,2),'s')
xlabel('time (Hour)')
ylabel('Percieved air quality (decipol)')

```

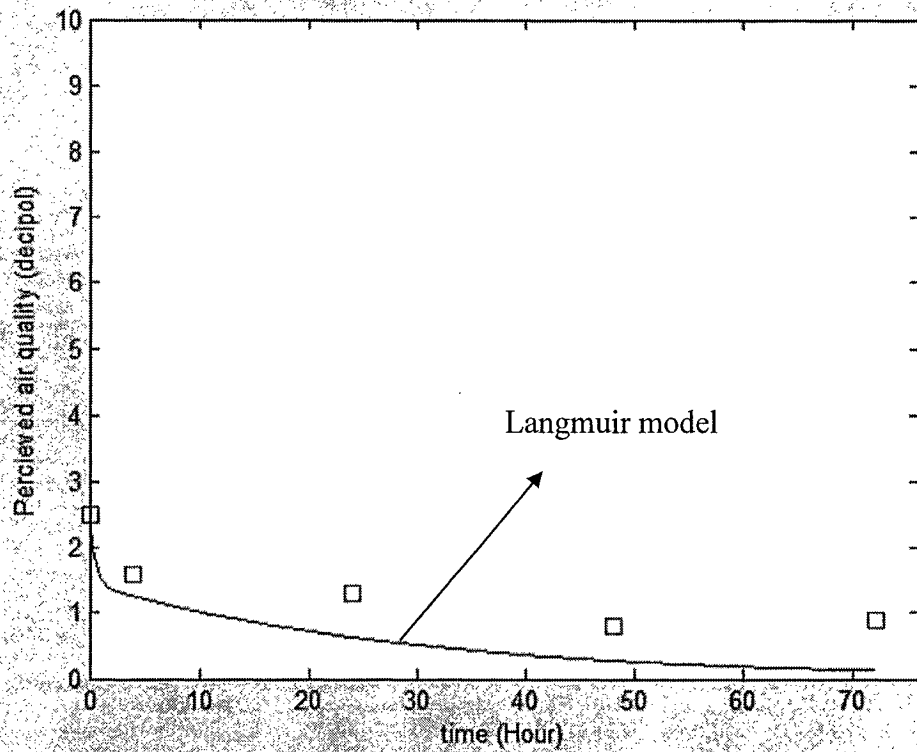
axis([min(t) max(t) yaxis])

2.2.1 Langmuir model fit to data that include the emission from painted gypsum boards



3. Desorption data for the room with samples of Semia after the linoleum was taken out of the room

```
ka=2.23;%(1);  
kd=0.13;%k(2);  
N=.8;  
L=0.6125;  
Ce=2.5;  
DATA=[0    2.5  
       4    1.6  
      24    1.3  
      48    0.8  
      72    0.9];  
b=0;  
yaxis=[0 10]
```



```

m=max(size(DATA));
t=0:.05:DATA(m,1);
Data=DATA-b*ones(m,1)*[0 1];
r1=((N+ka*L+kd)+sqrt((N+ka*L+kd)^2-4*N*kd))/2;
r2=((N+ka*L+kd)-sqrt((N+ka*L+kd)^2-4*N*kd))/2;
C=(Ce*((N-r2)*exp(-r1*t)-(N-r1)*exp(-r2*t))/(r1-r2));
plot(t,C,Data(:,1),Data(:,2),'s')
xlabel('time (Hour)')
ylabel('Perceived air quality (decipol)')
axis([ min(t) max(t) yaxis ])

```

Appendix D

Chemical emissions

1. Compounds emitted from linoleum

Chemical measurements of the concentrations of VOCs in outdoor air supplied to an office and in the office air with and without pollution sources (linoleum, aged sealant, wooden shelves with books) inside the office. (Data taken from Wargocki et al., 2002)

Compound	Odor threshold ($\mu\text{g}/\text{m}^3$) (Devos et al. 1990)	Office without pollution sources		Office with pollution sources	
		Outdoor air concentration ($\mu\text{g}/\text{m}^3$)	Office air concentration ($\mu\text{g}/\text{m}^3$)	Outdoor air concentration ($\mu\text{g}/\text{m}^3$)	Office air concentration ($\mu\text{g}/\text{m}^3$)
2-Propanone	34674	dl	dl	dl	4.68
Heptanal	23	dl	dl	dl	0.6
Hexanol	58	dl	1.15	dl	1.92
Ethanol	54954	dl	dl	dl	1.36
Phenol	425	0.58	dl	dl	1.69
Hexanal	58	dl	1.15	dl	1.92
Octane	27542	dl	dl	dl	dl
Nonanal	13	0.63	2.86	dl	3.09
Octanal	7	dl	0.84	dl	1.23
2-(2-butoxyethoxy) ethanol	n/a	dl	dl	dl	1.38
Xylene	1413	dl	1.62	dl	dl
2-Butanone	23442	dl	dl	dl	0.42
1,2- Propanediol	n/a	dl	dl	dl	1.1
Benzoic acid	n/a	1.1	1.37	0.64	1.25
Propanoic acid	110	dl	dl	dl	0.93
Decanal	6	0.6	2.0	dl	1.93
Benzaldehyde	186	1.06	1.11	0.73	1.13
1-Butanol	1514	dl	3.86	dl	3.8
2-Ethyl-1-hexanol	1318	dl	dl	dl	1.09
2-Methyl-1-propanol	2570	dl	dl	dl	2.74
Phenol	427	0.58	dl	dl	1.69
Pentanal	22	dl	dl	dl	1.29
1-Ethyl-2-methyl benzene	n/a	dl	dl	dl	0.59
Heptane	n/a	dl	dl	0.38	0.77
Pentadecane	n/a	dl	dl	dl	0.62

*These data were for an air exchange rate in the office was 1h^{-1}
dl: indicates that concentration were below detection limits

2. Compounds emitted from carpet

Chemical measurements of the concentrations of VOCs in outdoor air supplied to an office and in the office air with and without carpet inside the office (Data taken from Wargocki et al, 1999)

Compound	Odor threshold ($\mu\text{g}/\text{m}^3$) (Devos et al.1990)	Office without carpet		Office with carpet	
		Outdoor air concentration ($\mu\text{g}/\text{m}^3$)	Office air concentration ($\mu\text{g}/\text{m}^3$)	Outdoor air concentration ($\mu\text{g}/\text{m}^3$)	Office air concentration ($\mu\text{g}/\text{m}^3$)
toluene	5.9×10^3	9.25	10.5	13	13
benzene	12×10^3	3.25	8.5	3.25	7.15
butyldiglycol	n/a	2.02	2.6	1.9	3
butyldiglycol	n/a	1.98	9.1	1.86	9.65
phenol	427	1.9	2.55	2.85	3.5
acetone	34×10^3	60	75	135	125
acetic acid	363	24.5	39	29	60.5
hexanoic acid	60.3	1.2	2.6	1.25	1.55
octanoic acid	24	2.65	3	0.82	3.2
nonanoic acid	12.6	3.15	3.45	1.5	3.05
formaldehyde	1.1×10^3	3.78	16.8	1.83	14.4
hexanal	57.5	4.05	5.7	4.8	6.8
heptanal	22.9	NI	NI	1.41	3.05
nonanal	13.5	14.5	18	9.75	16
decanal	5.9	9.55	11.5	6.3	10
benzaldehyde	186	4.95	4.9	5.75	5.35
butyldiglycolacetate	n/a	0.67	4.3	0.63	5.1
hydrocarbon	n/a	1.8	6.3	3.2	9.55
isopropylmyristate	n/a	NI	NI	0.55	1.15
octanal	7.2	4.65	6.5	4.25	6.35
xylene	1.4×10^3	9.95	9.9	24.5	26
styrene	631	2.6	2.35	2.7	2.75
decane	4.4×10^3	NI	NI	1.55	2.3

NI: compound not identified

n/a: no odor threshold available