PREDICTIVE COSTING TOOL FOR CORROSIVE DRYWALL REMEDIATION IN THE STATE OF FLORIDA

By

PATRICK VERNON BEBOUT

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To my mom, for always encouraging me to pursue my dreams

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LIST OF ABBREVIATIONS

A/C	Air Conditioning
AMRC	American Management Resource Corporation
ATSDR	Agency for Toxic Substances and Disease Registry
C&D	Construction & Demolition
CaSO4 2H2O	Chemical Formula for Calcium Sulfate (Gypsum)
CDC	Centers for Disease Control and Prevention
CDBG	Community Development Block Grant
COS	Chemical Formula for Carbonyl Sulfide
CPSC	Consumer Protection Safety Commission
CS2	Chemical Formula for Carbon Disulfide
CTEH	Center for Toxicology and Environmental Health, L.L.C
EPA	U.S. Environmental Protection Agency
FDEP	Florida Department of Environmental Protection
FDOH	Florida Department of Health
FHA	Federal Housing Administration
GUI	Graphical User Interface
H2S	Chemical Formula for Hydrogen Sulfide
HEPA	High Efficiency Particulate Air
HUD	U.S. Department of Housing and Urban Development
KPT	Knauf Plasterboard Tianjin Co. Ltd.
MRL	Chronic Minimal Risk Level
ppbV	Parts per Billion Volume
ppm	Parts per Million
RfC	Chronic Reference Concentration

S	Elemental Symbol for Sulfur
Sr	Elemental Symbol for Strontium
SrS	Chemical Formula for Strontium Sulfide
SVOC	Semi Volatile Organic Compound
VBA	Visual Basic for Applications
VOC	Volatile Organic Compound

Abstract of Thesis Presented to the Graduate School
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Patrick Vernon Bebout

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Chair: James Sullivan
Cochair: Abdol Chini
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Corrosive drywall is a gypsum-based plasterboard that was manufactured in China and contains elemental sulfur and strontium. The drywall emits reduced sulfur gases in the chemical forms of hydrogen sulfide, carbonyl sulfide and carbon disulfide. These three gasses have been linked to the corrosion of metal components in homes including electrical wiring, refrigeration coils and fire safety devices creating a number of life safety issues. The import of Chinese drywall into the U.S. has been occurring since 1999. Estimates place the number of affected homes up to 38,000 and nearly two-thirds of those may be in the state of Florida. Several remediation protocols, including an interim protocol issued by the federal government, include the removal of all corrosive drywall from the home. This difficult and costly procedure will have a wide range of emotional, economic and environmental impacts. This paper presents the issues with corrosive drywall and provides Floridians an estimating tool to help gauge the financial burden of undertaking the interim federal remediation strategy.

CHAPTER 1
INTRODUCTION

1.1 Background

The full impact of the corrosive drywall problem in the U.S. is still emerging. As of May 7, 2010, the U.S. Consumer Product Safety Commission has received 3,082 reports from 37 different states, as well as the District of Columbia, Puerto Rico and American Samoa alleging that drywall manufactured in China is threatening health, corroding certain metal components in the home, or both (U.S. Consumer Product Safety Commission 2010a). These figures do not include cases that are reported at the state or local levels. Some estimates put the number of affected homes at 60,000 (Schmidt 2009). Regardless of the final count, there will be a significant emotional, economic and environmental impact involved in identifying and ultimately remediating the homes that contain corrosive drywall.

As of this writing, there is no single standard that has emerged for either the identification or remediation of homes affected by corrosive drywall. Yet, at least one company has been remediating homes since 2006 (Brinkman 2009d) and the federal government only recently released interim reports to provide guidance to homeowners for identifying and removing corrosive drywall (Tedder and McGuire 2009; U.S. Consumer Product and Safety Commission 2010b). One similarity between the remediation protocols offered by the private and public sectors is the recommendation to remove all of the source contaminant - the drywall - which contains traces of elemental sulfur (S) and elemental strontium (Sr). With a lack of inexpensive identification systems in place, this usually results in the replacement of all drywall in a home where at least a small amount of corrosive drywall exists.

Little is known as to whether the current remediation efforts will actually have the desired long term effect. Not enough time has passed to determine whether simply removing the corrosive drywall will stop certain metals from corroding in a home. Yet, if the protocols remain unchanged, it is evident that the removal of the corrosive drywall will be an expensive undertaking. If the remediators choose to replace all the ancillary building components such as insulation, copper electrical components, sheathing and other such materials, the cost will be even greater.

1.2 Statement of Purpose

This research aims to help Florida homeowners in two ways. First, it is to serve as an educational tool to help separate fact from fiction. The Internet is flooded with misinformation about the true nature of the corrosive drywall problem and how it should be handled. Over the last two years, the number of websites providing “information” about corrosive drywall has grown. Many of these sites simply use fear to coerce homeowners into accepting costly fixes that may or may not be effective (Federal Trade Commission 2009). It is of great importance that homeowners fully understand the drywall issue before committing to any identification or remediation efforts. Second, an estimating tool will be developed to help homeowners estimate the cost of a remediation effort. This tool will be created in Microsoft Office Access and generate estimates using cost data provided by R.S. Means.

1.3 Scope of this Paper

This paper will begin with the history of gypsum and its use in drywall. It will cover the practice of traditional gypsum mining and the more common use of synthetic gypsum. The paper will then explain how corrosive drywall is different than the drywall manufactured domestically and estimate the total scope of the problem. It will provide a history of how corrosive drywall was first identified and why the Chinese manufactured drywall was declared corrosive. This paper will explain the chemistry behind corrosive drywall and its effects on human health. It will provide details on the methods used to identify homes with the problem drywall and the different remediation protocols available. This paper will cover the financial resources available to help homeowners and discuss the environmental concerns with disposing of the remediated material.

This paper will also discuss the development of a remediation estimating tool. It will provide information about the development platform, the program flow and the core program logic. It will cover the inputs required from the user and discuss the testing procedures used to validate the tool’s functionality. Lastly, the paper will draw conclusions about the estimating tool and suggest future enhancements.

CHAPTER 2
LITERATURE REVIEW

2.1 Gypsum and Drywall

Drywall is a ubiquitous building product that is often called gypsum board, wallboard, plasterboard or rock lathe. The original gypsum board consisted of thin layers of plaster placed between four plies of wool felt paper. This board was patented in 1894 by Augustine Sackett who called his building product Sackett Board. In 1933, the patent was purchased by USG and Sackett Board was renamed Sheetrock. Drywall is most commonly used as a finishing cover over the structural members of walls and ceilings. Its widespread use is credited to the lower cost and shorter installation time needed to install and finish gypsum board over its predecessor, plaster (Armstrong et al. 2002). Unlike plaster, gypsum board is never wet during installation. Consequently, “drywall” became the popular name for the product.

A modern sheet of drywall consists of a thin layer of gypsum rock placed between two sheets of paper. Gypsum rock is between 100 and 200 million years old and has the chemically defined name of calcium sulfate ($CaSO_4 \cdot 2H_2O$). Gypsum is a sedimentary rock that collected through the evaporation of shallow water bodies throughout the world. One hundred pounds of gypsum rock contains about 21 pounds of chemically combined water. The rock is mined or quarried, crushed into a fine powder and heated to 350 degrees Fahrenheit until 75% of the water is removed in a process called calcining. To make drywall, the calcined gypsum is again remixed with water and additives into a slurry that is poured between two sheets of paper. The slurry recrystallizes back to its original rock state both chemically and mechanically bonding with the paper (Gypsum Association 2009).

Today, not all gypsum used in the production of drywall is naturally occurring. Japan and Europe have been using byproduct gypsum for nearly 30 years (Stav 2009). Byproduct gypsum, also known as synthetic gypsum, is a byproduct of coal-fired power plants. The coal combustion process creates a number of byproducts including fly ash, various impurities and exhaust gases. The exhaust gases are fed through limestone slurry (calcium carbonate) to remove sulfur dioxide. This “scrubbing”, or removal of sulfur dioxide, was a requirement of the 1970 Clean Air Act and its subsequent amendments. A chemical reaction occurs as the sulfur dioxide passes through the limestone slurry leaving the byproduct of calcium sulfate (gypsum). National Gypsum Company, a large U.S. manufacturer, claims that they receive a 97% pure form of gypsum from this process whereas mined gypsum is generally only 90% pure (Stav 2009). In 1991, synthetic gypsum accounted for only 4% of total gypsum production. By 2008, the number had escalated to 60% (Crangle 2009).

2.2 Defining Corrosive Drywall

Corrosive drywall, also known as Chinese drywall or imported drywall, is a gypsum-based drywall that contains chemicals not normally found in domestically produced drywall, most commonly strontium (Sr) and sulfur (S) (Singhvi 2009). Corrosive drywall off-gasses hydrogen sulfide (H2S), carbonyl sulfide (COS) and carbon disulfide (CS2) in a process that is accelerated by high humidity and heat (Gauthier 2009). This off-gassing produces odors similar to rotten eggs, corrodes copper and other metals and may have detrimental effects on human health (U.S. Consumer Product Safety Commission 2009a). The metal corrosion most commonly occurs in electrical switches and appliances with copper components such as refrigerators and televisions. Depending on the construction materials in the home, it may also affect piping for plumbing, gas lines and even fire suppression systems. The corrosion creates a risk for electrical fire, gas explosions, and may create an environmental hazard if certain refrigerants are released by damaged coils. It may also lead to the damage of smoke and carbon monoxide sensors, a hazard to life safety. Figure 2-1 provides four examples of metal corrosion in a home containing corrosive drywall. The black scaling found on these metals is an indicator of corrosive drywall in a home.

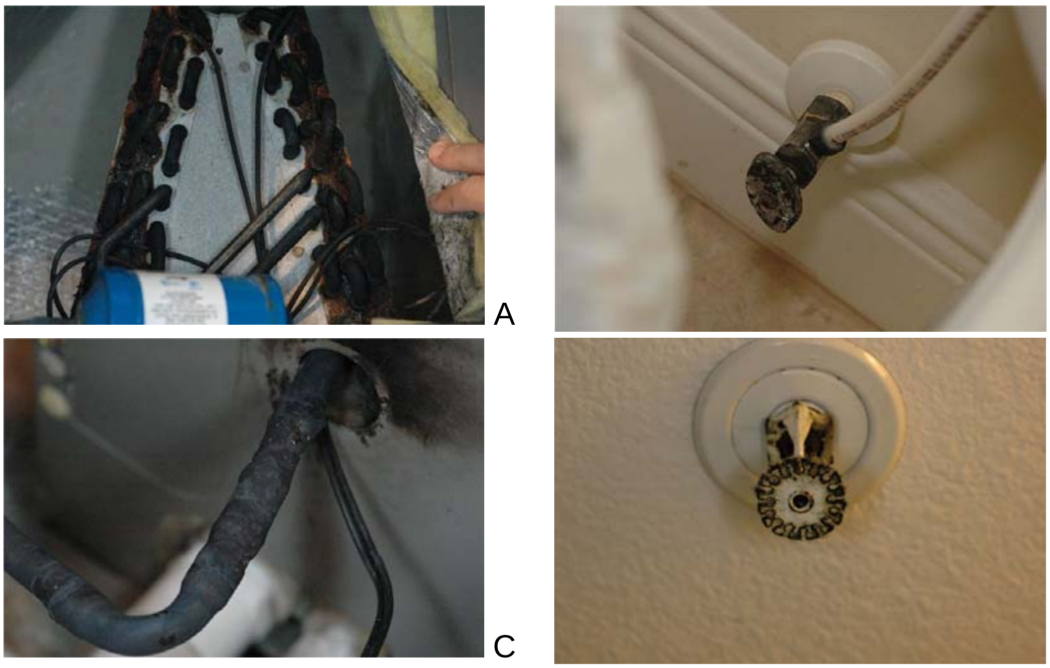

Figure 2-1. Examples of metal corrosion in a home containing corrosive drywall. A) refrigerator coil, B) water shut-off valve, C) copper water line, D) sprinkler head.

It is still unclear why such large quantities of Chinese drywall contain elemental sulfur, but several theories have been offered. One such theory has been presented by Knauf Plasterboard Tianjin Co. Ltd. (KPT), a major manufacturer of Chinese drywall. KPT has stated that some sulfur odors could be associated with the mined gypsum rock (Brinkman 2009c). KPT has also acknowledged that some of the corrosive drywall smelled like drywall made from natural gypsum in China. This theory is supported by an

Environ engineer, Dr. Gauthier, who believes the sulfur is from a sulfur vane that was entrained in the mined gypsum (Gauthier 2009).

2.3 Scope of the Problem

According to statistics compiled by the U.S. Department of Commerce, U.S. demand for gypsum wallboard peaked in 2006 at 3.69 billion square feet (Schmidt 2009). The U.S. demand for drywall was fueled by both a booming housing market and a rebuilding effort following the devastation of Hurricanes Katrina and Wilma in 2005 (Schmidt 2009). During this period, the United States helped satisfy domestic demand by importing significant amounts of drywall from China to construct and repair American homes. In 1955, only 50% of new homes in the U.S. used drywall while the other half still used plaster. Today, up to 98% of all new homes use drywall (Dushack 2009). Figure 2-2 illustrates that the quantity of imported Chinese drywall spiked in 2006 at nearly 218,100 metric tons (Crangle 2009).

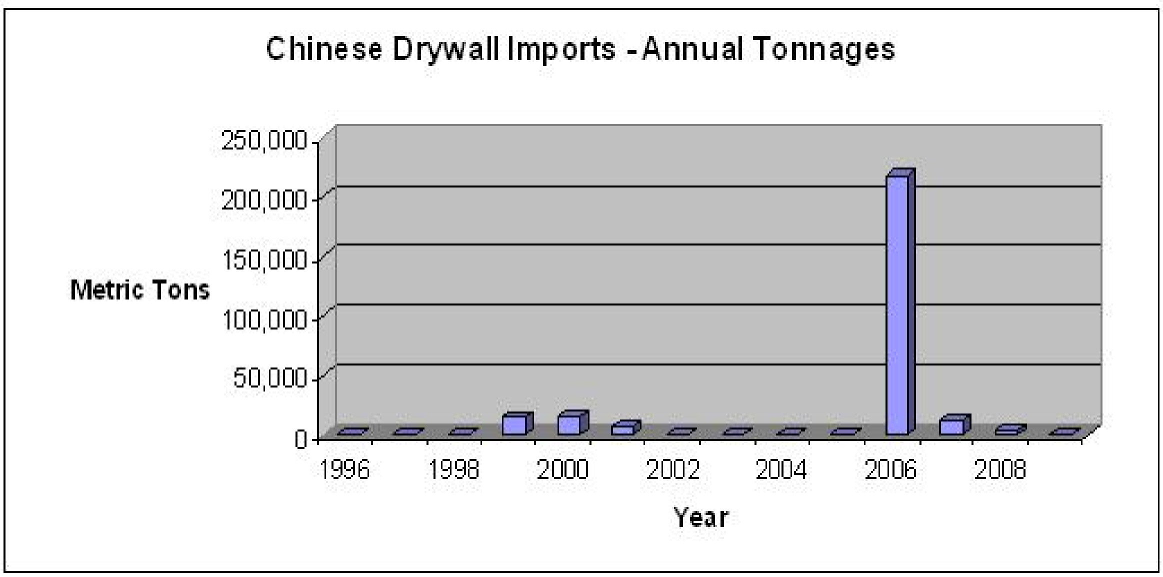

Figure 2-2. Total metric tons of imported Chinese drywall by year

There are approximately 200 drywall manufacturing plants in China, but the production from these plants is often extremely limited. In fact, some plants only generate a few dozen boards per year (Crangle 2009). The three largest Chinese manufactures of gypsum drywall are Lafarge, Saint-Gobain and Knauf Plasterboard Tianjin Co. Ltd. (KPT). KPT is the Chinese affiliate of German-based Knauf Gips. Both Lafarge and Saint-Gobain are French companies that have not exported Chinese drywall to the U.S.

The Consumer Protection Safety Commission (CPSC) staff has confirmed that at least 6,997,456 sheets of drywall were imported into the U.S. from China since 2006 and 28,778 sheets were imported into Guam, Saipan and American Samoa (U.S. Consumer Product Safety Commission 2009b). During that same time frame, KPT alone exported 67.3 million square feet of drywall to southern Florida (Brinkman 2009a). The total count continues to grow as the CPSC analyzes information received from consumers, builders, importers, manufacturers and suppliers of drywall to determine how much imported drywall is affected and where that drywall has been installed (U.S. Consumer Product Safety Commission 2009b).

The CPSC states the total number and location of effected homes is not known (Centers for Disease Control and Prevention 2009). Ervin Gonzalez of the law firm Colson Hicks Eidson estimates that, based on import records, up to 60,000 U.S. homes may be affected, about half of which are in Florida (Schmidt 2009). Rob Crangle, a minerals commodity expert with the U.S. Geographical Survey, estimates that up to two-thirds of all Chinese imports went to Florida (Crangle 2009). Figure 2-3 provides a breakdown of the Chinese drywall imports by port of entry (Crangle 2009). Sixty-seven percent of all Chinese drywall imports have entered the United States through Florida ports, specifically Miami and Tampa.

		Port of Entry							
Year	Total Imports (Metric Tons)	Miami (Metric Tons)	Miami (%)	Tampa (Metric Tons)	Tampa (%)	Total FL (Metric Tons)	Total FL (%)	Other US Ports (Metric Tons)	Other US Ports (%)
1999	15,481	4,326	28%	5,400	35%	9,726	63%	5,755	37%
2000	16,793	0	0%	10,012	60%	10,012	60%	6,781	40%
2001	7,756	0	0%	7,756	100%	7,756	100%	0	0%
2002	0	0	0%	0	0%	0	0%	0	0%
2003	14	0	0%	0	0%	0	0%	14	100%
2004	10	0	0%	0	0%	0	0%	10	100%
2005	369	369	100%	0	0%	369	100%	0	0%
2006	218,100	85,273	39%	68,927	32%	154,200	71%	63,900	29%
2007	12,373	1,963	16%	0	0%	1,963	16%	10,410	84%
2008	3,964	21	1%	0	0%	21	1%	3,943	99%
2009	656	22	3%	0	0%	22	3%	634	97%
	275,516	**91,974**	**33%**	**92,095**	**33%**	**184,069**	**67%**	**91,447**	**33%**

Figure 2-3. Total metric tons of imported Chinese drywall by port of entry

As of May, 2010, the CPSC has received reports from 24 states and the District of Columbia (U.S. Consumer Product Safety Commission 2010a). Figure 2-4 provides a geographic breakdown of incident reports sent to the CPSC by state. The largest number of complaints filed has come from the State of Florida (59%) followed by Louisiana (20%).

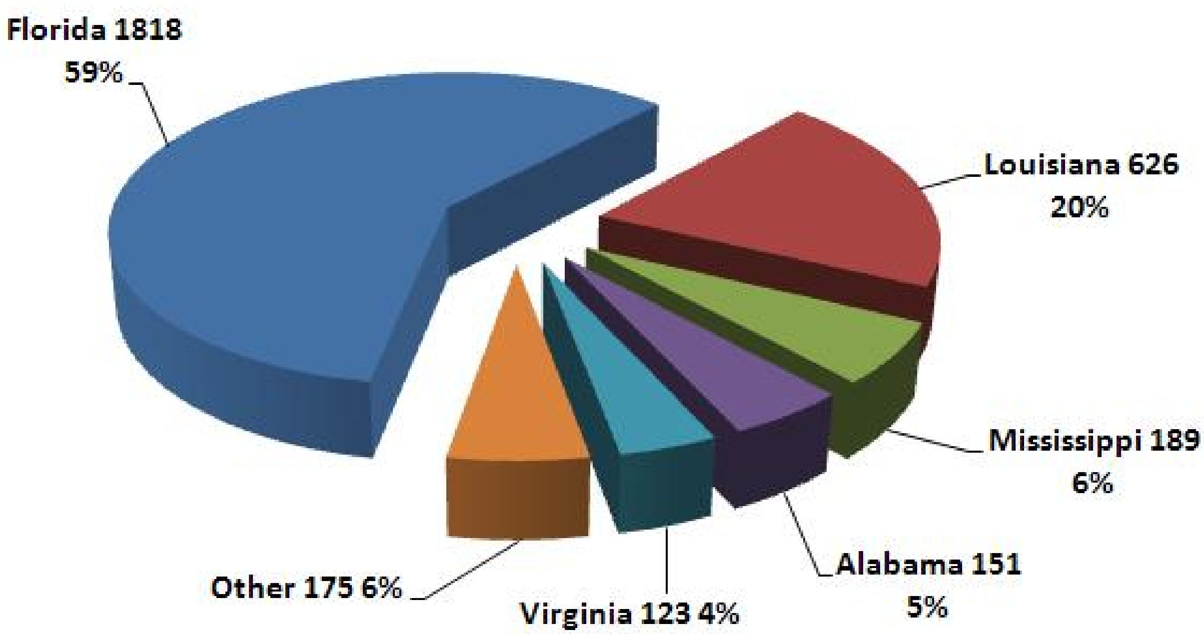

Figure 2-4. Number and percentage of reports filed to the CPSC from residents who believe their health symptoms or the corrosion of certain metal components in their homes are related to the presence of drywall produced in China (May 1, 2010).

2.4 Early Problem Identification

In 2004, the American Management Resource Corporation (AMRC), a Florida-based environmental health and safety consulting firm, made a connection between odor complaints and a possible problem with drywall in the state. The company had been hired to identify and remediate sulfur odors inside private homes and identified drywall as the source. At the time, no connection was established between the odor causing drywall and any particular manufacturer because of a lack of labeling on the wallboard. Jack Snyder, Principal and Senior Consultant for AMRC, stated that the connection to Chinese manufactures was not established for another two years because a manufacturing stamp stating the material origin was not always available (Schmidt 2009). Paul Brinkman, a writer for the South Florida Business Journal who has been following the defective drywall situation, makes similar claims that homebuilders and suppliers first became aware of the problem in 2006 (Brinkman 2009b). Knauf Plasterboard Tianjin Co. Ltd. (KPT) has also stated that claims started arising that same year (Brinkman 2009e).

A large homebuilder in Florida, Lennar Corp., hired a consulting firm to conduct tests to determine whether drywall installed in their houses was creating “rotten egg” odors in 2006. Testing was conducted by the Arlington, VA based Environ International on 79 Florida homes built with suspect drywall. The study found sulfur compounds in the air, but stated that the levels were well within health and safety limits or on par with outdoor air. Lennar claimed that the sulfur compounds were “far below even the most stringent government health and safety standards (Brinkman 2009c).”

Similarly, the largest supplier of Chinese drywall to Lennar, KPT, hired a consultant group to conduct indoor air quality tests. This testing was performed by the

Center for Toxicology and Environmental Health on 20 homes in Florida with discolored electrical wiring. The Center for Toxicology found results similar to Environ's tests. According to toxicologist Dr. Phillip Goad who oversaw his firm's testing, levels of carbonyl sulfide (COS) were in the range of salt marsh air and exposure to carbon disulfide (CS2) was well within safety levels set by The National Institute for Occupational Safety and Health (Brinkman 2009b).

In January of 2008, the Florida Department of Health's (FDOH) Indoor Air Programs Coordinator performed an assessment of 12 homes in the southern part of the state. The results of his tests revealed that the drywall contained strontium sulfide (SrS) and elemental sulfur (S). Additionally, high relative humidity and heat produced hydrogen sulfide (H2S), carbonyl sulfide (COS) and carbon disulfide (CS2). The tests results did not say or speculate whether the levels found were dangerous to human health or capable of causing property damage (Brinkman 2009f).

It was in December of 2008 that the U.S. Consumer Product and Safety Commission (CPSC) began receiving complaints from homeowners about obnoxious smells and the corrosion of metal components in their homes. A team of CPSC investigators was sent to Florida to walk several houses under study by the FDOH. While in Florida, they observed first hand the symptoms associated with the corrosive drywall. On April 14, 2009, a meeting was held in Washington, D.C. to assemble the Federal Interagency Task Force.

2.5 The Federal Response

The federal response to the corrosive drywall problem is being managed by the Federal Interagency Task Force (Task Force) led by the Consumer Product Safety Commission (CPSC). The CPSC is working with the Environmental Protection Agency

(EPA), Agency for Toxic Substances and Disease Registry (ATSDR) and the U.S. Department of Housing and Urban Development (HUD). The CPSC is also working with numerous state and local agencies such as the Florida Department of Health.

The CPSC is currently conducting research in three areas. The first area is an evaluation of the relationship between the drywall and reported health symptoms. The second area is an evaluation of the relationship between the drywall and electrical and fire safety issues in the home. The third is a tracing of the origin and distribution of the drywall. This multi-pronged, concurrent approach includes interviewing consumers about their particular drywall problems, collecting samples of degraded household components, and establishing links between foreign manufacturers and domestic consumers (U.S. Consumer Product Safety Commission 2009a).

The speed of the federal investigation is limited by the scientific research being performed. Additionally, the CPSC has identified the following as inherent obstacles to their research:

- How much problem drywall there is in any house, given that it is already installed, likely painted and may not be clearly marked. The drywall could fill the home or be just a few sheets.
- Health symptoms are similar to colds, allergies or reactions to other pollutants sometimes found in homes. As such, it is important to carefully determine if the reported symptoms are related to the drywall and not any other environmental factors or pollutants in the home.
- The presence and extent of corrosion within a house, or even within a room, appears inconsistent.

2.6 Chemistry of Corrosive Drywall

On March 5, 2009, a teleconference was held between the U.S. Environmental Protection agency (EPA), Agency for Toxic Substances and Disease Registry (ATSDR) and the Florida Department of Health (FDOH). The FDOH provided background information on the research conducted to date, including the studies performed by Knauf Plasterboard Tianjin Co. Ltd. and Lennar. As an outcome of the call, ATSDR asked the EPA to conduct an elemental comparison of drywall manufactured in China against drywall manufactured in the United States. The comparison was done in an EPA laboratory.

The sample sizes were small for the experimental and control groups. The FDOH selected two wallboard samples from homes where the drywall manufacturer was known to be Chinese for the experimental group. The EPA purchased four U.S. manufactured samples from stores in Edison, N.J for the control group. All four U.S. samples were from different manufactures, and the two Florida samples were also from different manufacturers.

To prepare the samples for testing, paint was scraped from the two boards taken from Florida homes. Then, all six boards had the paper removed from the solid gypsum material and the paper was placed in six separate glass jars. The gypsum material from each of the six samples was also placed in a separate glass containers. The paper material was analyzed for metals, semi volatile organic compounds (SVOCs) and formaldehyde. The solid gypsum material was analyzed for metals, SVOCs, volatile organic compounds, formaldehyde, sulfide, water soluble chlorides, total organic carbon, pH and loss on ignition. An additional optical microscopic examination was conducted to determine the presence of fly ash. The EPA felt the following results were significant (Singhvi 2009):

- Sulfur was detected at 83 parts per millions (ppm) and 119 ppm in the Chinese drywall samples. Sulfur was not detected in the four US-manufactured drywall samples.

- Strontium was detected at 2,570 ppm and 2,670 ppm in the Chinese drywall samples. Strontium was detected in the US-manufactured drywall at 244 ppm to 1,130 ppm. Total acid soluble sulfides were not detected in any samples.
- No fly ash was detected in the Chinese manufactured drywall.

2.7 Health Concerns

One of the more controversial aspects of the corrosive drywall problem is the effect of the reduced sulfur compounds on human health. Ongoing research is being conducted as to whether the levels and types of gasses capable of corroding metal in the homes are the cause of reported health problems. Many of the affected homeowners have filed complaints that the drywall in their homes has had a negative impact on the health of the occupants. These complaints include asthma, respiratory irritation, breathing difficulties, coughing, insomnia, eye irritation, headaches, sinus problems, sleep apnea, sneezing, rashes, allergies and sore throats (Centers for Disease Control and Prevention 2009).

The research conducted to-date has not shown that the corrosive drywall is specifically responsible for any of these health problems. Dr. Michael McGeehin of the Centers for Disease Control and Prevention believes that irritants are typical in any home, regardless of whether the home contains corrosive drywall. These irritants are even more prevalent in new buildings and come from a large variety of sources including paints, carpeting, and cleaning agents. Upper respiratory problems are one of the more common effects of these irritants (McGeehin 2009).

Additionally, the chemicals being off-gassed by the corrosive drywall are found in many places, the vast majority being outside of the affected homes. Natural sources of sulfur-containing chemicals include ocean water, salt marshes, soil, human breath, vegetation and forests, wetlands, biomass burning and human diet (protein metabolizing). The sulfur gasses can also be generated by cigarette smoke, wastewater treatment plants and car exhaust.

Dr. David Kraus, the State Toxicologist for the Florida Department of Health, led a study to evaluate occupant exposure to chemicals in affected homes. The study was performed in homes that met the case definition outlined by the state of Florida for a home containing corrosive drywall and in control homes in the same neighborhood that did not meet the case definition. During Phase I of the study, grab samples where taken from all the homes in the morning and at night. The samples would be tested for sulfur-containing gasses as well as other volatile organic compounds. Phase II of the study captured the same air samples but over a 24 hour period to study possible diurnal effects.

The results of his study found that the homes that met the case definition had reduced sulfur gasses. Hydrogen sulfide (H2S) was found at 5.72 parts per billion volume (ppbV), carbonyl sulfide (COS) at 4.14 ppbV and carbon disulfide (CS2) at 2.5 ppbV. No sulfur gasses where found in the control homes. According to Dr. Kraus, these chemical levels do not pose a hazard to occupants. Additionally, many of the other chemicals found in both the test and control homes are known respiratory irritants and malodorants (Kraus 2009).

Lynn Wilder, an Environmental Scientist with the Agency for Toxic Substances and Disease Registry Division of Health Studies, also performed air sampling in both Florida and Louisiana. In Florida, the tests were conducted in two experimental homes and two control homes. In Louisiana, four experimental homes and two control homes were used. Time-weighted sample data was collected to test for a wide variety of chemicals that included reduced sulfur compounds, VOCs, amines, aldehydes and others.

The results of this study found low levels of hydrogen sulfide (H2S) both inside and outside of the experimental homes and control homes. These levels periodically exceeded the odor threshold but were below health-based guidelines. Carbonyl sulfide (COS) and carbon disulfide (CS2) were also found in low levels both inside and outside of only one experimental home. These levels were below the health-based guidelines. The study concluded that the irritant and malodors compounds were present. As such, sensitive individuals exposed to these chemicals could see an exacerbation of respiratory problems. These individuals may also experience ear, nose and throat irritation. However, the source of these chemicals could not be directly linked to the drywall and the overall contaminant levels are commonly found in all U.S. homes (Wilder 2009).

A third study was performed by the Center for Toxicology and Environmental Health, L.L.C (CTEH). Although the company was hired by Knauf Plasterboard Tianjin Co. Ltd., CTEH was to conduct an independent, third-party indoor air quality investigation. The study was performed on 42 homes that had a documented presence of Chinese drywall, foul odors and copper discoloration. The study also covered 13 control homes without any corrosive drywall.

The results found that the average level of carbonyl sulfide (COS) was 3.0 ppbV in the subject homes, 8.1 ppbV in the control homes and 1.6 ppbV in the outside air. The maximum reading in the subject homes was 16.6 ppbV. To put these numbers in perspective, the study provided that the average reading of COS from human breath is

92 ppbV. The level in ocean air varies between 6 and 8 ppbV and the air over salt marshes is approximately 24 - 73 ppbV. Animals exposed to 200,000 to 300,000 ppbV for six hours a day, five days a week for twelve weeks showed no side effects. The company was unable to find a correlation between this sulfur compound and corrosive drywall (Goad 2009).

Carbon disulfide (CS2) was only found in seven of the 42 homes with a maximum reading of 3.2 ppbV. This compound is also found in human breath with an average of 24 ppbV. The Chronic Minimal Risk Level (MRL) is 300 ppbV. The ATSDR defines the MRL as “an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse human effects (noncarcinogenic)” following an exposure lasting a year or longer. A second standard sets the Chronic Reference Concentration (RfC) at 220 ppbV. According to the EPA, an RfC is “an estimate, with uncertainty spanning at least an order of magnitude, of a daily [inhalation] exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during a lifetime (Goad 2009).”

Hydrogen sulfide (H2S) was found in only 1 test home and 1 control home with a reading of 4.0 ppbV for the test home and 1.7 ppbV for the control home. This compound naturally occurs in many foods such as beef, onion, coffee, cabbage and chicken. Readings taken above a wine bottle can read up to 14.6 ppbV. The MRL for H2S is 20 ppbV. The EPA subchronic RfC (7 year exposure) is 7 ppbV. The EPA chronic RfC (lifetime exposure) is 1.4 ppbV (Goad 2009).

The study drew several conclusions about the chemicals found in the air samples. First, the levels of detected sulfur compounds were all below levels associated with negative health effects. Second, the individual chemicals are not related to the presence or absence of Chinese drywall. Third, the chemical levels in the homes do not present a public health concern (Goad 2009).

2.8 Identification

Identifying homes with corrosive drywall is a process that continues to evolve and change with new research. It requires performing a number of visual inspections, smell tests and often complicated lab work. It is not as simple as finding a sheet of drywall labeled “Made in China” since not all Chinese drywall is corrosive drywall. Today, there are many different approaches to identifying homes with corrosive drywall and some are more complicated than others. The following section describes the identification procedures offered by the State of Florida and the Federal Government.

2.8.1 State of Florida

Since March of 2009, the Florida Department of Health (FDOH) has provided an online tool for identifying homes in the state that meet the “case definition” of a house with drywall associated corrosion. This definition continues to evolve as more information is provided by federal and state researchers. The first case definition was released on March 30, 2009 and the second on December 18, 2009. As of this writing, FDOH is still providing the second revision of their case definition via the Internet.

It is important to note that FDOH is very clear that the “sole purpose of this case definition is to help identify homes that are affected by corrosion associated with drywall emissions (Florida Department of Health 2009a).” The case definition is not intended to evaluate health risks to occupants, identify levels of exposure, is not regulatory in nature and not required for identification purposes.

2.8.1.1 Case definition (03-30-09)

The first case definition (3/30/2009) strategy by the FDOH provided residents a simple online tool to help determine whether a home met the state's case definition for an effected home. Five yes/no questions were posed to the homeowner that covered odors, reoccurring and costly A/C problems, charcoal or black corrosion of copper Freon lines, manufacturing markings on the drywall indicating a Chinese company and a professional inspection to confirm the presence of corrosion on electrical wiring or A/C coils. If the home was built after January 1, 2004 and a "yes" answer was given to two or more of these questions, the home met the case definition. If the home was built before that same date but three or more "yes" answers were given, the home also met the case definition (Florida Department of Health 2009c). This identification approach was originally suggested and endorsed by the Consumer Protection and Safety Commission (U.S. Consumer Product Safety Commission 2010a).

2.8.1.2 Case definition (12-18-09)

The most current release of the Case Definition (12/18/2009) allows homeowners to rank their homes as possible, probable or confirmed cases of containing corrosive drywall. The homeowner can conduct the Criteria 1 review which has three steps. The first step requires the homeowner to identify whether their home was constructed or renovated with new drywall since 2001. The second step requires an inspection of the copper tubing of the air condition evaporator coil for black corrosion. The third step is to identify other traces of metal corrosion in the home from electrical ground wires to copper pipes and silver and copper jewelry. If all three indicators are met, the house has met the definition of a "possible case" and a trained professional can proceed with Criteria 2 and 3 inspections.

For a Criteria 2 inspection, the trained professional is asked to identify supporting indicators. If there are markings on the backside of the drywall stating China as the country of origin, the home has met the “probable case” definition. The definition can also be met if the professional finds Strontium levels exceed 2,000 ppm in the drywall. At this stage, it is still considered unconfirmed whether the drywall is the cause of the corrosion in the home. The confirmation is achieved by the trained professional performing a Criteria 3 inspection.

A Criteria 3 inspection provides three alternatives for identifying a home as a “confirmed” case. Only one of these tests must have positive results to meet the “confirmed” case definition. The first tests must show that the gypsum core of the drywall contains elemental sulfur exceeding 10 ppm. The second method is to test the drywall headspace for reduced sulfur gas emissions (H2S, COS, CS2). The third test is a qualitative analysis of suspect drywall for its ability to cause corrosion / blackening of copper under controlled conditions, indicating drywall samples from the home emit gasses capable of corroding copper.

2.8.2 The Federal Government

The Federal Interagency Task Force states that it does not believe there is a definitive test to determine whether a home has problem drywall. However, the Task Force does suggest contacting the builder about the materials used in construction. It also provides some sentinel indicators that are indicative of the problem drywall. These include the smell of rotten eggs, corrosion of metal components such as copper coils and possible health problems. It also states that the “Made in China” labeling and a grayish colored gypsum core may be indicative of a problem.

Two members of the Task Force, the Consumer Product and Safety Commission and Housing and Urban Development, released the report Interim Guidance - Identification of Homes with Corrosion from Problem Drywall on January 28, 2010 (Tedder and McGuire 2009). It is intended as a preliminary interim guidance based on the information that is available at this time. Much like the Florida Department of Health Case Definition (12/18/2009), the identification procedure is a multi-step approach intended to logically identify problem homes.

The first step of the procedure is to perform a threshold, or visual, inspection of the house. The inspection is to identify any blackening of copper electrical wire and/or air evaporation coils. The second step is to identify the installation of new drywall in the home between 2001 and 2008. The installation could have occurred during new construction or during renovations. If both of these visual inspections show positive results, the second step of the procedure can be conducted.

The second step of the procedure is to find corroborating evidence. The importance of this second step is to eliminate other confounding factors that may have contributed to the corrosion in the home. According to the interim report, it is possible to misclassify homes because of other possible sources of metal corrosion such as volatile sulfur compounds from sewer gas, well water, and outdoor contaminants that may enter the home independent of the drywall in the home. A total of six corroborating factors are provided. If the drywall was installed between 2005 and 2008, only two of the corroborating factors need to be met. If the drywall was installed between 2001 and 2004, four of the factors need to be met to meet the case definition. The corroborating factors include:

- Corrosive conditions in the home, demonstrated by the formation of copper sulfide on copper coupons (test strips of metal) placed in the home for a period of 2 weeks to 30 days or confirmation of the presence of sulfur in the blackening of the grounding wires and / or air conditioner coils.

- Confirmed markings of Chinese origin for drywall in the home.

- Strontium levels of drywall core found in the home (i.e. excluding the exterior paper surfaces) exceeding 1200 ppm.

- Elemental sulfur levels in samples of drywall core found in the home exceeding 10 ppm.

- Elevated levels of hydrogen sulfide, carbonyl sulfide and/or carbon disulfide emitted from samples of drywall found in the home when placed in test chambers using ASTM Standard Test Method D5504-08 or similar chamber or headspace testing.

- Corrosion of copper metal to form copper sulfide when copper is placed in test chambers with drywall samples taken from the home.

2.9 Remediation

Remediation is the process of removing corrosive or damaged components from a home and then replacing the components that have been removed. Consequently, it is a two-step process employing a phase of demolition as well as a phase of reconstruction. Currently, a variety of remediation approaches exist that offer a broad range of cost, effort and sophistication for repairing homes afflicted with corrosive drywall. This variety exists because no single remediation protocol has been adopted by the private and public sectors. The Florida Department of Health (FDOH) does not endorse any specific method or technique and only recently did the Federal Government release an interim protocol for remediation.

2.9.1 The State of Florida

In their first Hazard Assessment, FDOH considered the removal and replacement of suspected or known source material (the drywall) to be the only proven and effective treatment method. However, state officials had also received occupant reports and conducted preliminary tests that indicated other porous materials such as fabric may absorb and re-emit corrosive gases (cross-contamination), but they expressed uncertainty whether concrete and lumber had that level of porosity. The FDOH stated that ozone treatments, coatings and air cleaners are considered suspect and needed additional scrutiny (Florida Department of Health 2009c).

With the release of their revised Case Definition (12/18/2009), the stance of the FDOH had changed on their views of remediation. According to the most recent website update, the FDOH "has not examined remediation methods and does not endorse any specific methods or techniques to conduct an effective remediation of affected homes (Florida Department of Health 2009a)."

2.9.2 The Federal Government

On April 2, 2010, the Federal Interagency Task Force released the report Interim Remediation Guidance for Homes with Corrosion from Problem Drywall. This interim report is the first protocol by the federal government which outlines the four areas of the home to perform remediation efforts. The areas include the problem drywall as well as the systems that drywall-induced corrosion may have caused a safety concern for the inhabitants. The four areas with safety concerns include all fire alarm safety devices (including smoke alarms and carbon monoxide alarms), all electrical components and wiring (including outlets, switches and circuit breakers), and all gas service piping and fire suppression sprinkler systems.

The federal approach further states that in most cases all drywall should be removed from the home until the practical and scientific challenges of identifying the specific corrosive sheets can be overcome. If these challenges are met, and no other corroborating evidence of corrosion exists, it is an option to leave the drywall in place. The government also acknowledges that further research may add or subtract from the components that need replacement. In the future, this may eliminate copper wiring with an insulated shield but could add copper piping for water lines. The government does not have sufficient evidence to show that cross-contamination between components currently exists or that high efficiency particulate air (HEPA) vacuuming is required. However, it encourages all property owners to consider the remediation approaches used by other professionals before committing to a single course of action.

2.9.3 Protocols from Litigation

The private sector has been performing remediation practices for several years. These have been performed by homeowners, builders and other parties interested in removing the corrosive drywall. Many of these practices have been proprietary in nature and details of the procedures have been unavailable to the general public. However, recent litigation at the federal level has presented a clearer picture of the remediation protocols being used in the private sector by builders. These trials have been presided over by U.S. District Court Judge Eldon E. Fallon from New Orleans. Reporting from the trial has shown that remediation strategies used by different builders is not consistent.

There have been two trials presided over by Judge Fallon that have helped establish legal precedents for the remediation of homes containing corrosive drywall. The first trial was brought by seven Virginia families whose homes contain contaminated Knauf Plasterboard Tianjin Co. Ltd. (KPT) drywall. During the trial, two independent Virginia contractors calculated estimates of $82 per square foot, or $172,000 for a typical 2,000 square foot home (Kessler 2009d). These costs did not include the expenses already incurred by the homeowners which included coil replacements, loss of electronics, relocation expenses, loss of income and diminished home values. The estimates were based on an approach suggested by Dean A. Rutila, a senior principal with the environmental consulting firm Simpson, Gumpertz & Heger. Rutila contends that the corrosive effects are “unacceptable from the perspective of life safety and the building code (Kessler 2009d).” Furthermore, a proper remediation “requires the replacement of all drywall, electrical equipment and all copper and silver components in the houses (Kessler 2009d)." KPT was ordered to pay $2.6 million to the Virginia families but never responded to the suit.

Another lawsuit was begun on March 15, 2010. This was the second trial in a massive litigation suite against KPT. Again, the case was presided over by Judge Fallon. The plaintiffs were Tatum and Charlene Hernandez, homeowners from Mandeville, LA. Their home was built with Tianjin drywall, a product of KPT. One of the more important outcomes of the trial was a determination of the remediation efforts needed in effected homes.

On April 28, 2010, Judge Fallon decided in favor with the Hernandez family awarding the couple $164,000 to fix their house. The protocol outlined by the judge called for the replacement of all drywall, the entire electrical network, the HVAC system and damaged appliances and electronics. The Hernandez family was seeking a more thorough repair of their home that would have cost $200,000 while KPT argued that the remediation could be done for $58,000. This was the first lawsuit in which a remediation protocol was outlined. Judge Fallon also asked KPT to perform his remediation protocol on the homes of the seven Virginia families from the first lawsuit.

KPT still contends that the drywall remediation can be achieved by removing only the source contaminant - the drywall. All ancillary building components, such as plumbing, electrical and appliances, can be left intact. Where corrosion is evident on the electrical systems, wire clipping and cleaning can be conducted. This approach is considered “a very simple project” by Roy M. Carubba, the expert hired by KPT to perform cost calculations of the remediation (Kessler 2009c).

2.9.4 The Homebuilders

Both Lennar Homes and Beazer Homes are national homebuilders that have admitted to building homes with corrosive drywall. Since acknowledging the problem, both builders have been performing proprietary remediation protocols for their customers. During the second KPT trial, both builders were called to the stand to discuss how their companies were performing remediation. It was clear from the proceedings that a lot of similarities existed between the two protocols but they were not entirely consistent with one another.

Lennar Homes has been conducting remediation since acknowledging a drywall problem in 2006 (Brinkman 2009d). The homebuilder has not publicly disclosed the extent of their efforts or their methodology for identifying and remediating the drywall. However, during the second KPT trial, details of their efforts became clearer. Approximately one year ago, Lennar made a major change to their remediation protocol and began replacing all electrical systems. This change began once the builder realized corrosion was occurring on insulated wires (Kessler 2009b). Lennar is also replacing condensers outside of the home to avoid a problem known as “short cycling.” Short cycling occurs when the inside compressor fails to work properly causing additional stress on the condenser unit which may lead to additional damage. To address lingering dusts or odors, Lennar performs vacuuming with high-efficiency particulate absorbing (HEPA) equipment.

During the second KPT trial, Beazer's Florida Vice President Ray Phillips testified that corrosion was occurring behind the insulation of electrical wire. Consequently, Beazer remediation protocols also require the complete removal of electrical systems in homes undergoing their protocol (Kessler 2009a). Beazer protocols also call for the replacement of cabinets and wood flooring which is likely to get damaged during remediation. Beazer is not replacing the condenser unit (Kessler 2009c). Phillips also noted that he had experienced lingering odors weeks after remediation occurred. Consequently, the company now performs pressure washing within the homes prior to replacing any materials (Kessler 2009b).

2.9.5 Private Sector Businesses

As the scope and costs of the corrosive drywall problem rise, the number of businesses involved in the process of identifying and remediating problem homes has also increased. The techniques employed by these companies vary greatly in their level of effort and scientific authenticity. Several firms have invested large sums of money into research and efforts to get protocols approved by various standards organizations while others are simply fly-by-night operations. Given this, the FTC issued a very direct warning to homeowners to question any business that offers a solution to the corrosive drywall issue (Federal Trade Commission 2009).

2.10 Financial Burden

The U.S. Department of Housing and Urban Development (HUD) has announced that Federal Housing Administration (FHA)-Insured families experiencing problems with corrosive drywall may be eligible for financial assistance. HUD has instructed FHA mortgage lenders to extend temporary relief to families that need to make home repairs. This relief is not typically available under an informal forbearance or repayment plan and is called FHA Type 1 Special Forbearance. The relief would include one or more of the following:

- Suspension or reduction of payments for a period sufficient to allow the borrower to recover from the cause of default;
- A period during which the borrower is only required to make their regular monthly mortgage payment before beginning to repay the arrearage; or
- A repayment period of at least six months.

HUD is instructing lenders that no late fees are to be assessed while the borrower is making timely payments under the terms of the Special Forbearance Plan. The total arrearage for a Type 1 Special Forbearance cannot exceed 12 months of delinquent payments. Lenders can review borrower applications and make a determination as to the most appropriate loss mitigation tool including loan modification, partial claim, or FHA Home Affordable Modification Program.

HUD has also provided a second method for assisting communities where corrosive drywall is present. This program is called the Community Development Block Grant (CDGB). Historically, CDBG has helped to support local efforts to rehabilitate homes through grants, loans, loan guarantees, and other means. In addition, CDBG may also support code enforcement, acquisition, clearance and remediation activities, and relocation. All CDBG-assisted activities must meet one of the program's three national objectives: provide benefit to low and moderate income persons; eliminate slums or blighting conditions; or address an immediate threat to the health or welfare of the community. In this case, the corrosive drywall is considered an immediate threat to the welfare of the community.

2.11 Disposal Concerns

2.11.1 Disposal of Drywall in Florida

Although the many different remediation protocols currently being practiced throughout the U.S. vary greatly in their details, one commonality holds them altogether. They almost all require the full removal of the corrosive drywall. Although the total amount of corrosive drywall imported into the U.S. remains unknown, some groups estimate that nearly 60,000 homes in the United States may have been constructed with this tainted product. Of that, nearly 35,000 homes may have been in the state of Florida alone (U.S. Consumer Product Safety Commission 2010b). If the average 2,000sf home contains 7.3 metric tons of drywall (Crangle 2009), the total weight of corrosive drywall in Florida could reasonably approach 256,000 metric tons if total remediation of these homes is performed. The disposal of this product requires considerable resources and falls under the authority of the Florida Department of Environmental Protection (FDEP).

The FDEP first became involved in the corrosive drywall issue after being contacted by the Florida Department of Health in February of 2009. Dr. Tim Townsend, a professional engineer and professor at the University of Florida, collected samples of corrosive drywall and provided them to the FDEP for materials classification. By April of 2009, the FDEP had determined that the corrosive drywall was not characteristic of a hazardous waste. A month later, the Interim Drywall Disposal Guide was offered to the public by the FDEP to provide recommended procedures for disposing of all drywall throughout the state. The guide does not differentiate between corrosive drywall and domestically produced drywall. According to Florida Statutes (Section 403.703(6), F.S.), gypsum wallboard is considered part of construction and demolition (C&D) debris.

Consequently, it is legal to dispose of this material at any permitted C&D Disposal site throughout the state.

In any landfill, all gypsum has the potential to release hydrogen sulfide gas under anaerobic conditions with water and organic material. The calcium sulfate from the gypsum can be consumed by sulfur reducing bacteria which can produce hydrogen sulfide gas (H2S). The presence of hydrogen sulfide gas at landfills became a concern following the clean-up after the hurricanes of 2004 and 2005 (U.S. Consumer Product Safety Commission 2010b). Several C&D disposal sites throughout the state experienced high levels of hydrogen sulfide gases, which, in some cases, created potentially dangerous situations to Floridians living in the vicinity of these sites. It is believed the damaged drywall was dumped with large amounts of vegetative debris which led to the high concentrations of gas. Today, the state is still wary of creating similar conditions if the solid waste stream is again flooded with large amounts of drywall.

Unlike typical drywall, there were other concerns about the gases surrounding the corrosive drywall. Hydrogen sulfide is only one of three gases found in most effected homes. The other two are carbonyl sulfide and carbon disulfide. Additionally, tests found elevated traces of strontium between 2 to 8 times greater than the levels typically found in domestically manufactured products (Tedder 2009). However, neither the gases nor the Strontium were sufficient to create a direct exposure problem (Tedder 2009).

Given the total potential for creating hydrogen sulfide, the interim disposal guide provides two alternatives that divert the drywall from typical disposal chains. The first and most recommended approach is to take the corrosive drywall to a Class I landfill where cover is applied daily and the site has a gas control system that helps mitigate odor problems (the process of adding cover requires the placement of soil to the top of the landfill and compacting it to a depth of 6” using heavy machinery). Additionally, Class I landfills are typically much larger and spread the debris over greater areas. This spreads out the drywall reducing the chances of the creation of hydrogen sulfide. If the loads are taken to a C&D or Class III site, the guide suggests applying a daily cover where possible but not exceeding at least one cover per week. Additionally, the loads should be spread out over as great an area as possible.

The guide is not intended to be a standard, rule or requirement and was developed only to provide guidance to the District staff. If C&D disposal sites choose not to apply cover, the will not be subject to enforcement actions but may experience increased levels of gas monitoring to ensure the safety of the site.

2.11.2 Landfill Alternatives

According to Dr. Townsend at the University of Florida, there is only one simple alternative to avoid placing drywall into a landfill - simply don’t do it (Townsend 2009). But in order for this option to make sense, there must be alternative markets available for recycling drywall. If they don’t exist, the product will inevitably return to the ground.

Four of the more typical approaches to recycling drywall include using the removed drywall to produce new drywall, as an additive to Portland cement, for agriculture and for use as a construction material (land applications, road base). However, serious consideration must be given to any recycling method that would return the drywall to a location where it could be used in the vicinity of certain metals. Unless the elemental sulfur is removed, the drywall could potentially continue to off-gas for many years (Pool 2009). Given this, during the 2009 Technical Symposium on

Corrosive Drywall in Tampa, Mr. Richard Tedder of the FDEP stated that he “does not recommend recycling (Tedder 2009).”

If the drywall does return to the landfill, there are options for controlling the production of hydrogen sulfide gas. The first option is to control the environment. By eliminating water and organic materials, the sulfur reducing bacteria will not be able to live. If this is not possible, killing the bacteria may be feasible with the introduction of an inhibitor such as lime. If the bacteria can not be stopped, the next step would be to capture or divert the hydrogen sulfide gas. This can be accomplished through the use of a soil cover or a gas collection system. Depending on the levels of hydrogen sulfide present, simply masking the odor until it dissipates may suffice (presuming, of course, the levels are sufficiently low not to cause bodily harm).

Over the last ten years, the Hinkley Center for Solid and Hazardous Waste Management at the University of Florida has experimented with the disposal of drywall under varying conditions. Their tests have shown that the solutions presented by Dr. Townsend have proven successful under the test conditions (e.g., lime-amended sand used as a cover) (Townsend 2009). Recently the Hinkley Center received a grant from the U.S. EPA to examine and identify and additional disposal issues with corrosive drywall.

CHAPTER 3
METHODOLOGY

The Interim Remediation Guidance for Homes with Corrosion from Problem Drywall ("Guide") is the first remediation protocol provided by the federal government. The Guide specifies four areas of the home where corrosive drywall remediation should occur. These areas include the problem drywall as well as the systems that drywall-induced corrosion may have caused a safety concern for the building occupants. The four areas with safety concerns include all fire alarm safety devices (including smoke alarms and carbon monoxide alarms), all electrical components and wiring (including outlets, switches and circuit breakers), and all gas service piping and fire suppression sprinkler systems.

For many Florida homeowners, calculating the cost of a remediation that satisfies the federal interim protocol is a difficult task. The protocol covers many areas in the home and accurate construction cost information is not readily available. If the estimate is not self-performed, one means for obtaining a cost estimate would be to ask a professional contractor. Even then, however, it is difficult to gauge the accuracy of an estimate without comparing it to a second or third estimate which takes additional time and effort. As such, a remediation estimating tool ("Estimating Tool") will be developed to provide Floridians with the means to generate a rough estimate of construction costs if they opt to perform a remediation that does not exceed federal guidelines.

The Estimating Tool will be a software program that provides a remediation estimate based on specific house details provided by the user and cost information provided by the R.S. Means publication 2009 Square Foot Costs. It will use several algorithms to multiply the values entered into the program by the user against the R.S.

Means square foot costs to generate a total cost of remediation. The program will be robust enough to allow additional cost data to be added, edited and deleted by the user. The user will also have the capability to enter a Florida location factor which will allow the national average costs provided by R.S. Means to be adjusted to a specific Florida locality.

3.1 Platform

The Estimating Tool will be developed using Microsoft Office Access ("Access"). Access is a pseudo relational database management system from Microsoft that combines the relational Microsoft Jet Database Engine with a graphical user interface and software development tools. The choice to use Access as the development platform is made for three reasons. First, the final program will be a stand-alone application that can be emailed to any interested parties. Second, the look-and-feel of the program will be similar to other Microsoft programs which many computer users are already familiar with. Third, the program will be robust enough to allow other programmers to add, change or remove functionality. All source code, written in Visual Basic for Applications (VBA), will remain accessible through the Access interface.

3.2 User Inputs

The Estimating Tool will require the user to perform a number of quantity take-offs, measurements and observations of the house being estimated. Since the application uses a database to store the information, the user can perform the required steps while using the program in a limitless number of sittings. All information stored in the program will be saved until the user chooses to delete it.

The first responsibility of the user is to provide a rough estimate of the total square footage of finished space in the home. This number should exclude unfinished areas often found in garages, storage spaces, attics and unfinished basements. The total square footage of finished space will be used by the program to prepare estimates on electrical, sprinkler and demolition services.

Next, the user must create an inventory of each room in the house and record specific features about that room. Only rooms containing drywall should be included in the inventory. The features of the room required by the program include the room's overall dimensions in terms of length, width and ceiling height. Also, the number of smoke alarms and carbon monoxide detectors should be recorded as well as their type and manufacturer. Information on the thickness of the ceiling drywall, attic insulation and the type of finish of the ceiling should also be noted.

After the room information is entered into the Estimating Tool, information about the walls within each room is required by the program. All walls covered with drywall, including interior partition walls, should be included in this step. The length and height of the wall are needed, as well as whether the wall has drywall on one or two sides. Other observations to be noted are the thickness of the drywall used on the wall, the type of finish and the type of insulation (if applicable).

The last step required of the user is to record information about the openings found in each wall. Openings most commonly include doors and windows. However, an opening can also include a permanent bookshelf, woodwork or any other feature that removes an area of drywall from the wall. Only the length and width of these openings are required by the Estimating Tool. The total square footage of drywall calculated for the home will exclude the total square footage of the openings.

3.3 Square Foot Costs

The database back-end of the Estimating Tool will be designed to capture two major groups of information. The first group includes the specific dimensions and materials of the house. These are collected by the program user and entered into the database through the graphical user interface (GUI). The second group of information includes the actual square foot costs related to the various stages and components of the remediation. These include square foot costs for replacing drywall, insulation, electrical systems and others. The first release of the Estimating Tool will include at lease one square foot estimate for each category and stage of remediation based on information provided by R.S. Means in their publication 2009 Square Foot Costs. The data provided in the first release is based on information from the year 2009. As construction costs change with time, it will be necessary to update these values. Additionally, the specific house being entered into the program may contain elements not pre-populated in the first program release. Under these circumstances, the user will have the capability to update and add additional values to the square foot construction costs through the GUI.

3.4 Program Flow

Figure 3-1 visually demonstrates the program flow of the Estimating Tool. Once a user opens the program on his or her computer, a window will appear. This is the main navigation window in the program that will allow the user to perform one of two functions. The first function is to go to the estimating window where the user will be able to create a new estimate, edit an existing estimate, delete an old estimate or run the estimate report. The second function is to perform maintenance on the construction costs in the database. The maintenance functionality allows the program to be updated as building costs change over time or the user wishes to add additional costs. The user can edit or delete the construction costs that have been pre-populated into the program or add additional ones if needed for their specific homes. By providing this option, it is not necessary to hard-code any variables into the source code of the program. There will be a total of nine windows used in the maintenance of the cost data in the program.

If the user opts to work on an estimate, they will be brought to the estimate window where they can add, edit or delete existing estimates. Each estimate is linked to one specific house entered into the program by the user. As such, once all the required home information is entered, the user can navigate to the window to view the Remediation Cost Report. The Remediation Cost Report provides the user with the cost estimates for each category of the remediation procedure, a total cost and a cost per square foot of finished space.

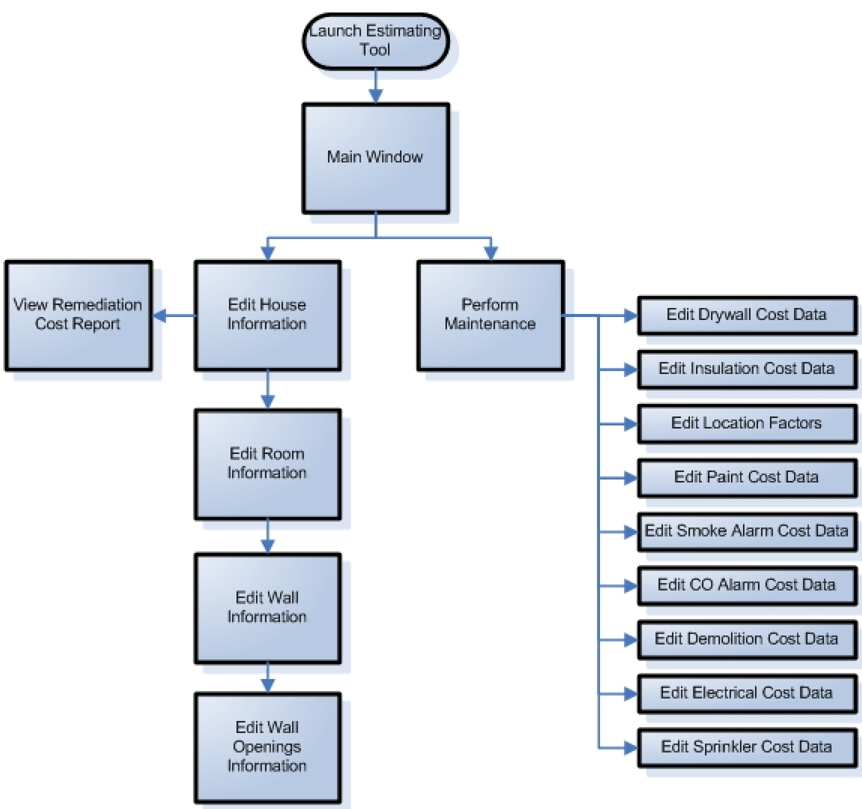

Figure 3-1. Program flow of the Estimating Tool

3.5 Main Program Logic

The core programming logic for the Estimating Tool is executed every time the user chooses to view the Remediation Cost Report. Before any information is displayed to the user, the program will run through the linear steps and logical loops that are shown in Figure 3-2. The first step of this logic is to query the database for specific information about the house being estimated including the total square footage of finished space. The total square footage of finished space will allow the program to create remediation estimates for the costs of demolition, electrical work and sprinkler replacement (if applicable).

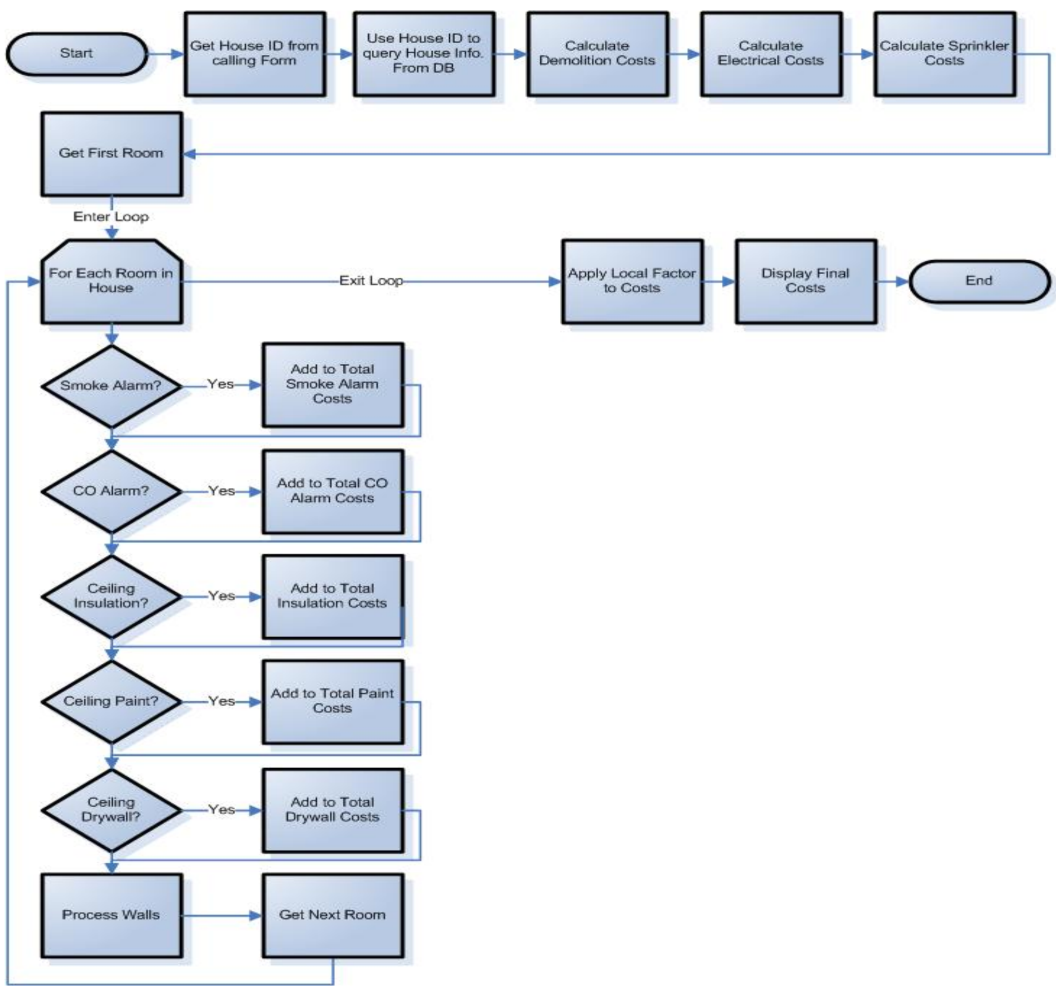

Figure 3-2. Core logic of the Estimating Tool

After the first three estimates are calculated, the program will enter its first logical loop, looping through every room in the house. The room data will provide costs for smoke detectors, carbon monoxide detectors, ceiling insulation, ceiling paint and ceiling drywall. In each first level loop, the program will begin the second level loop illustrated in Figure 3-3.

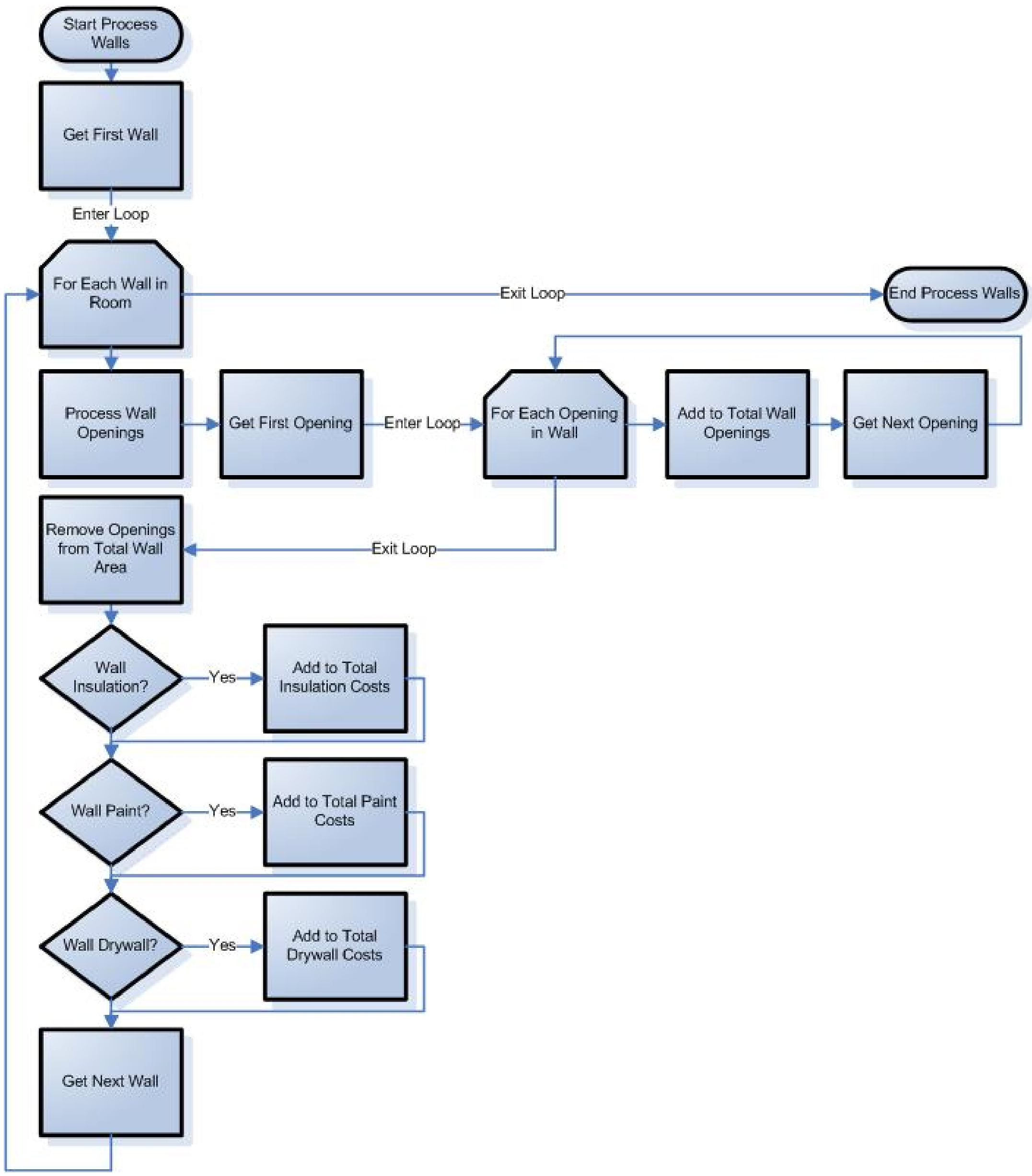

Figure 3-3. Second and third level loops of the core programming logic for the Estimating Tool

The second level loop is responsible for gathering information on the walls entered for each room. The first step in this loop is to collect the total area of any openings in the walls. These openings will be subtracted out of the total drywall in the home and are collected in a third level loop. Until the program encounters the last opening entered by the user, the core logic will keep adding together the openings to get a total area of these openings. Next, costs associated with insulation, paint and drywall are added to the total costs of these three building components collected for the house. This process is then repeated for each wall in the room. When the program fails to encounter any more walls, the logical loop is exited and the processing returns to the first level loop.

After all the rooms, walls and openings have been processed, the information gathered and calculated by the program will be displayed to the user through the Remediation Cost Report. The Remediation Cost Report will be the final output of the program. The report will be designed to be printed for future reference by the program user. It will contain basic project information (such as project name and location), square foot calculations and final remediation costs for each component being evaluated by the program.

CHAPTER 4
RESULTS

4.1 Testing Methodology

In order to properly test the Estimating Tool, it was necessary to design a test house that contains all the elements that are included in the functionality of the program. As shown in Figure 4-1, the test house consists of two rooms and all interior walls and the ceiling are assumed to be covered in drywall. A total of three doors and two windows are included in the test house. The doors and windows serve as “openings” that can be subtracted out of the total drywall calculations. In addition, a small partition wall is included in the north room. The partition is needed to test the double-counting feature of the Estimating Tool. The double-counting feature is used when a wall has drywall on two sides. Under these circumstances, the square footage of drywall on that wall is counted twice by the program.

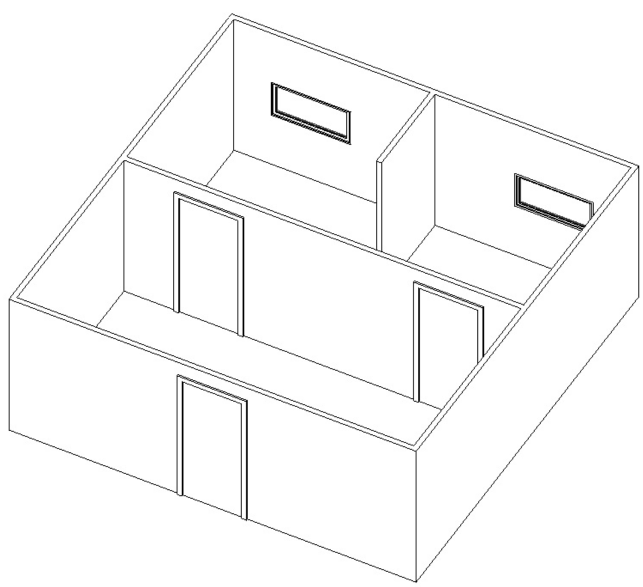

Figure 4-1. 3D representation of the house used to test the Estimating Tool

The overall dimensions of the rooms are shown in Figure 4-2, the building floor plan. The wall with the two windows is on the north side of the building and the entrance is found on the south side. All three doors are 3 feet wide and both windows are 4 feet wide. The interior dimensions of both rooms are 10 feet long by 20 feet wide. The interior partition that splits the north room is 5 feet in length. The south room is named Room 1 and the north room is named Room 2. As shown in Figures 4-3 and 4-4, the north and south elevations, all doors are 7 feet in height, windows are 2 feet in height and the building walls are 8 feet in height.

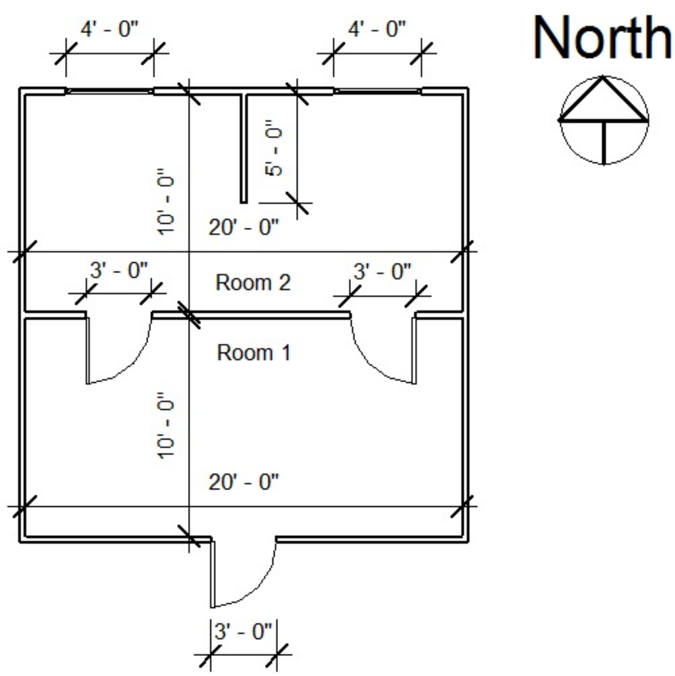

Figure 4-2. Floor plan of the house used to test the Estimating Tool

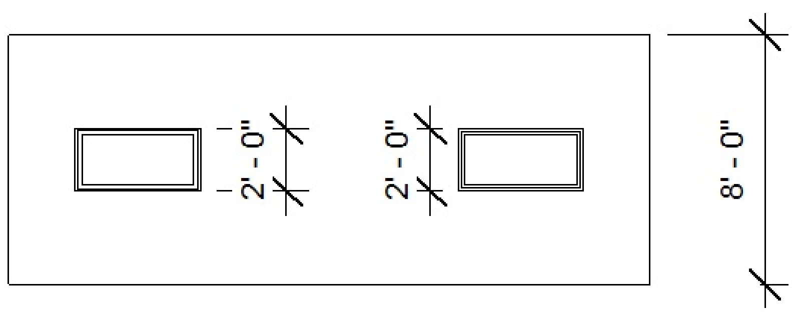

Figure 4-3. North elevation of the house used to test the Estimating Tool

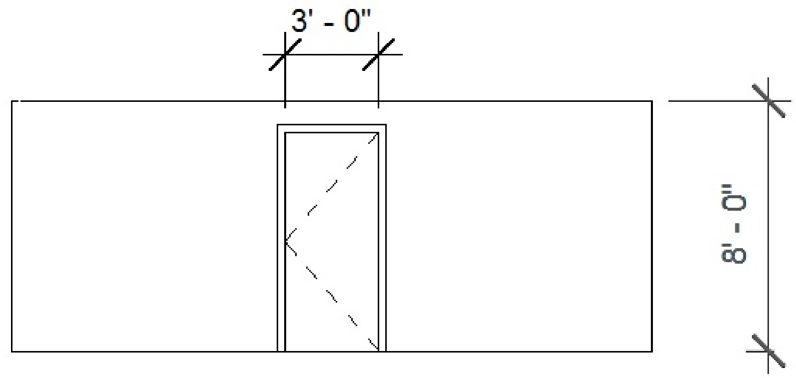

Figure 4-4. South elevation of the house used to test the Estimating Tool

In addition to assigning physical dimensions to the test house, it was also necessary to make assumptions about the materials and systems included in its construction. The following material selections and assumptions were made for the test house:

- The test house has a total of 400 square feet of finished space
- Demolition costs $6.00 per square foot
- Electrical work costs $16.50 per square foot
- The test house has a wet pipe sprinkler system ($4.78 / sf)
- The drywall used on the walls is a standard drywall, 1/2" in thickness ($1.39 / sf)
- The drywall used on the ceilings is a standard drywall, 5/8" in thickness ($1.41 / sf)
- All exterior walls are insulated with a fiberglass insulation at 3 1/2" of thickness ($1.00 / sf)
- All ceiling spaces are insulated with a fiberglass insulation at 6" of thickness ($1.22 / sf)
- None of the interior walls are insulated
- All drywall on the walls has been painted with a primer and two coats of paint ($1.03 / sf)
- All drywall on the ceiling has been painted with a primer and only one coat of paint ($0.76 / sf)

- Each room has 1 First Alert SA302CN Smoke Detector ($23.00 / unit)
- Each room has 1 Kidde / Lifesaver 9C05 CO Detector ($48.00 / unit)
- The closest location factor to the test house is Jacksonville, FL (.8)

4.2 Expected Results

There are a total of 16 fields on the Remediation Estimate window whose values result from the information entered and selected by the user, cost data provided by the R. S. Means publication 2009 Building Construction Cost Data, and calculation logic provided by the program. In order to validate that the Estimating Tool performs as designed, it was necessary to manually calculate expected values for each of the 16 fields before running the program on the test house. It will then be possible to compare the manual calculations to the actual output of the program. The manually calculated value for each of the 16 fields follows.

Field: Gross Wall Area (sf). Gross wall area is the total area of all the walls in the house without subtracting out any openings such as the doors or windows. As shown in Figure 4-4, the expected gross wall area of the test house is 1,040 square feet. This total is the summation of the individual areas of each of the 10 walls.

Gross Wall Area				
Room #	**Wall Orientation**	**Length (ft)**	**Height (ft)**	**Area (sf)**
Room 1	North	20	8	160
Room 1	South	20	8	160
Room 1	East	10	8	80
Room 1	West	10	8	80
Room 2	North	20	8	160
Room 2	South	20	8	160
Room 2	East	10	8	80
Room 2	West	10	8	80
Room 2	Partition - East	5	8	40
Room 2	Partition - West	5	8	40
Total				**1,040**

Figure 4-4. Expected total gross square footage of the wall area for the test house calculated by the summation of the area of each wall

Field: Gross Openings (sf). The "gross openings" of a house is the total area of all the wall openings entered by the program user. In the test house, this includes three doors and two windows. As shown in Figure 4-5, the "gross openings" is 79 square feet.

Gross Openings					
Room #	**Wall Orientation**	**Type**	**Height (ft)**	**Width (ft)**	**Area (sf)**
Room 1	South	Front Door	7	3	21
Room 1	North	Int. Door 1	7	3	21
Room 1	North	Int. Door 2	7	3	21
Room 2	North	Window 1	2	4	8
Room 2	North	Window 2	2	4	8
Total					**79**

Figure 4-5. Expected total square footage of the wall openings in the test house calculated by the summation of the openings in each wall

Field: Net Wall Area (sf). The net wall area is simply the subtraction of Gross Openings from Gross Wall Area, or 1,040 square feet less 79 square feet which equals 961 square feet for the test house.

Field: Ceiling Area (sf). Ceiling area is the total area of all the ceilings in the house which are entered per room. In the test house, there are a total of two rooms which generate a total ceiling area of 400 square feet as shown in Figure 4-6.

Ceiling Area			
Room #	**Width (ft)**	**Length (ft)**	**Area (sf)**
Room 1	20	10	200
Room 1	20	10	200
Total			**400**

Figure 4-6. Expected total square footage of the ceiling area in the test house calculated by the summation of the ceiling area of each room

Field: Total Drywall (sf). Total drywall is the summation of Net Wall Area and Ceiling Area. For the test house, the sum of 400 square feet and 961 square feet is 1,361 square feet.

Field: Electrical Estimate ($). The electrical estimate is generated by multiplying the total square footage of finished space by the cost of electrical work per square foot.

In the test house, the assumption is made the cost of installing new electrical work is $16.50 per square foot. Figure 4-7 shows the total cost of a new electrical system in the test house costs $6,600.

Electrical Estimate		
Total Area (sf)	Cost Per SF	Total Cost
400	$16.50	$6,600.00

Figure 4-7. Electrical estimate of the test house based on the product of user selected cost data and total square footage

Field: Demolition Estimate ($). The demolition estimate is generated by multiplying the total square footage of finished space by the cost of demolition work per square foot. In the test house, the assumption is made the cost of demolition is $6.00 per square foot. Figure 4-8 shows the total cost of the demolition in the test house costs $2,400.

Demolition Estimate		
Total Area (sf)	Cost Per SF	Total Cost
400	$6.00	$2,400.00

Figure 4-8. Demolition estimate of the test house based on the product of user selected cost data and total square footage

Field: Sprinkler Estimate ($). The sprinkler estimate is generated by multiplying the total square footage of finished space by the cost of installing a sprinkler system per square foot. In the test house, the assumption is made the cost of the sprinkler system is $4.78 per square foot. Figure 4-9 shows the total cost of the sprinkler in the test house costs $1,912.

Sprinkler Estimate		
Total Area (sf)	Cost Per SF	Total Cost
400	$4.78	$1,912.00

Figure 4-9. Sprinkler estimate of the test house based on the product of user selected cost data and total square footage

Field: Drywall Estimate ($). The drywall estimate is generated by multiplying the square footage of a particular type of drywall by the cost for that particular type as selected by the user. Then, all the individual costs are added together to create a grand total which is displayed in the Drywall Estimate field. In the test house, there are two different types of drywall used. The drywall used on the walls is a half inch in size ($1.39 per square foot) and the drywall on the ceilings is made from a heavier 5/8" type ($1.41 per square foot). Figure 4-10 shows the resulting grand total for the two types costs $1,898.

Drywall Estimate			
Type	**Area (sf)**	**Cost Per SF**	**Total Cost**
1/2" Drywall (Net Wall Area)	961	$1.39	$1,335.79
5/8" Drywall (Ceiling Area)	400	$1.41	$564.00
Total			**$1,897.79**

Figure 4-10. Drywall cost estimate of the test house based on the product of user selected drywall types and total square footage of drywall used

Field: Insulation Estimate ($). The insulation estimate is generated by multiplying the square footage of a particular type of insulation by the cost for that particular type. Then, all the individual costs are added together to create a grand total that is displayed in the Insulation Estimate field. In the test house, there are two different types of insulation used. The exterior walls use 3 1/2" insulation ($1.00 per square foot) and the ceiling has 6" insulation ($1.22 per square foot). There is no insulation in the interior walls. Figure 4-11 shows the resulting grand total for insulation costs $1,091.

Insulation Estimate					
Location	**Gross Area (sf)**	**Less Openings (sf)**	**Net Area (sf)**	**Cost Per SF**	**Total Cost**
Exterior Wall - North	160	16	144	$1.00	$144.00
Exterior Wall - South	160	21	139	$1.00	$139.00
Exterior Wall - East	160	0	160	$1.00	$160.00
Exterior Wall - West	160	0	160	$1.00	$160.00
Ceiling	400	0	400	$1.22	$488.00
Total					**$1,091.00**

Figure 4-11. Insulation cost estimate of the test house based on the product of user selected insulation types and the net square footage of wall area

Field: Paint Estimate ($). The paint estimate is generated by multiplying the square footage of a particular type of paint by the cost for that particular type. Then, all the individual costs are added together to create a grand total displayed in the Paint Estimate field. In the test house, there are two different types of paint used. The walls are painted with a primer and two coats of paint ($0.76 per square foot). The ceilings are painted with a primer and only one coat of paint ($1.03 per square foot). Figure 4-12 shows the resulting grand total for the two types costs $1,292.

Paint Estimate			
Type	**Area (sf)**	**Cost Per SF**	**Total Cost**
Primer + 1 Coat (Ceilings)	400	$0.76	$304.00
Primer + 2 Coats (Walls)	961	$1.03	$989.83
Total			**$1,291.83**

Figure 4-12. Paint cost estimate of the test house based on the product of user selected paint types and the net square footage of wall area

Field: Smoke Alarms ($). The cost of the smoke alarms is calculated by multiplying the total number of smoke alarms by the cost associated with each type. The test house has a total of two smoke alarms, one per room. Both alarms cost $23 each. The total cost of smoke alarms is $46.

Field: CO Alarms ($). The cost of the carbon monoxide (CO) alarms is calculated by multiplying the total number of CO alarms by the cost associated with each type. The test house has a total of two CO alarms, one per room. Both alarms cost $48 each. The total cost of CO Alarms is $96.

Field: Subtotal (National Avg.) ($). The subtotal value is the summation of all the previous 8 cost estimates. Because the cost data provided by R.S. Means has not been adjusted to a specific Florida locality in this field, it is a national average value. Figure 4-13 shows that all the individual costs sum to $15,339.

Subtotal (National Average)	
Field Name	**Field Value**
Electrical Estimate ($)	$6,600.00
Demolition Estimate ($)	$2,400.00
Sprinkler Estimate ($)	$1,912.00
Drywall Estimate ($)	$1,897.79
Insulation Estimate ($)	$1,091.00
Paint Estimate ($)	$1,291.83
Smoke Alarms ($)	$46.00
CO Alarms ($)	$96.00
Total	**$15,338.62**

Figure 4-13. Subtotal of remediation estimate based on national average construction costs

Field: Total (Location Adjusted) ($). The location adjusted total is the product of multiplying the national average costs found in the Subtotal field by the location factor selected by the user. In this case, the test house was given a location factor of Jacksonville, FL which has a value of 0.8. Multiplying $15,339 by 0.8 creates a product of $12,271.

Field: Cost Per SF ($). The cost per square foot value results from dividing the location adjusted total displayed in the Total (Location Adjusted) field by the finished square footage of the house. For the test house, it is the resultant of dividing $12,271 by 400 square feet which results in a value of $30.68.

4.3 Actual Results

The test house was entered into the Estimating Tool per the specifications of the test procedure. All rooms, walls and openings were dimensioned per the floor plans and elevations. All systems and materials selected for the test house were inputted into the program identically to the test procedure. The program was then prompted to generate a Remediation Cost Report for the test house. Figure 4-14 shows the output provided by the Estimating Tool.

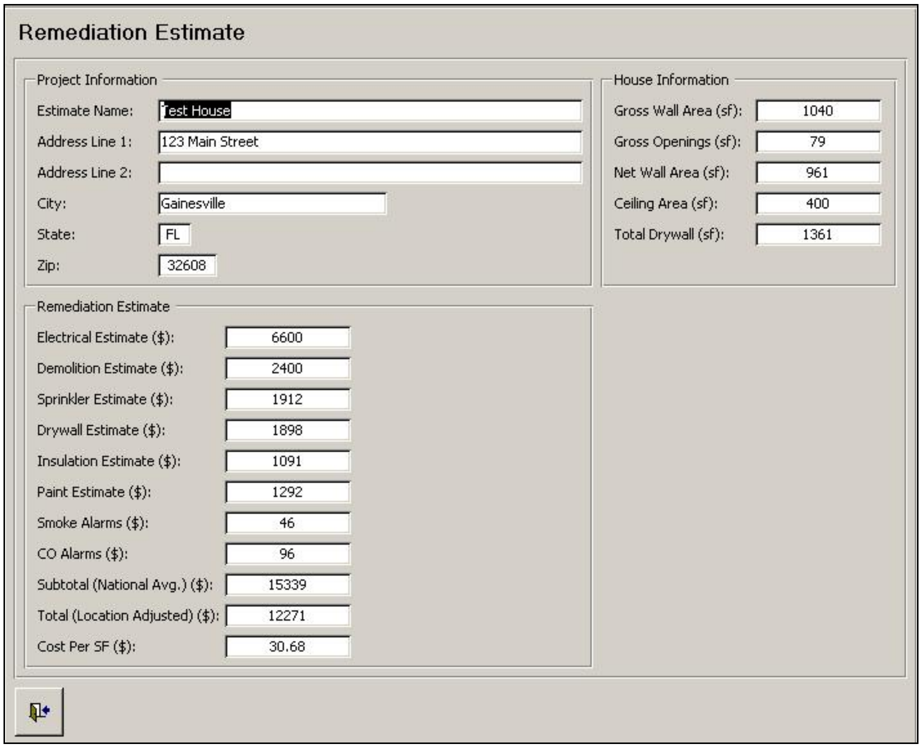

Figure 4-14. Remediation Estimate window of the Estimating Tool displaying the costs associated with the test house

When all the manually calculated expected results for each field are compared to the actual results for that particular field, no differences are found. This indicates that the program performs as designed. Figure 4-15 shows a comparison of the expected results versus the actual results for each calculated field in the Remediation Cost Report.

Comparison of Expected and Actual Values			
Field Name	**Expected Value**	**Actual Value**	**Match**
Gross Wall Area (sf)	1040	1040	Y
Gross Openings (sf)	79	79	Y
Net Wall Area (sf)	961	961	Y
Ceiling Area (sf)	400	400	Y
Total Drywall (sf)	1361	1361	Y
Electrical Estimate ($)	6600	6600	Y
Demolition Estimate ($)	2400	2400	Y
Sprinkler Estimate ($)	1912	1912	Y
Drywall Estimate ($)	1898	1898	Y
Insulation Estimate ($)	1091	1091	Y
Paint Estimate ($)	1292	1292	Y
Smoke Alarms ($)	46	46	Y
CO Alarms ($)	96	96	Y
Subtotal (National Avg.) ($)	15339	15339	Y
Total (Location Adjusted) ($)	12271	12271	Y
Cost Per SF ($)	30.68	30.68	Y

Figure 4-15. Comparison of expected and actual cost data for the test house based on data provided by the testing procedure

4.4 Comparison of Test House to the Average House

The domestic manufacturer of drywall, USG Corporation, manufactures 1/2" *Sheetrock* which weighs 1.6 pounds per square foot and 5/8" Sheetrock which weighs 2.2 pounds per square foot (USG 2009). According to the Estimating Tool, the 400 square foot test house with a simple configuration of two rooms, three doors, two windows and a small partition wall has a total of 1,361 square feet of drywall. If the entire test house were made from these two Sheetrock products, the 961 square feet of walls would weigh 1,538 pounds. The ceiling would weigh 880 pounds. Summed together, the total weight of drywall in the test house would be 2,418 pounds. If the test house were increased in size by a factor of 5 to accommodate 2,000 square feet of finished space, the drywall would weigh approximately 12,090 pounds or 5.5 metric tons.

It has been estimated that a single 2,000 sf home contains 7.3 metric tons of drywall (Crangle 2009) which is 33% more weight than the 2,000 square foot test house. This difference may be explained by the small number of partitions found in the test house. The test house contains only two interior partitions whereas an average home, which would contain multiple rooms, would have more interior partitions increasing the total square footage of drywall.

CHAPTER 5
CONCLUSIONS

The first release of the Estimating Tool has a number of limitations that can make its use cumbersome, maintenance intensive, possibly inaccurate and not fully accessible. However, each of these limitations can be addressed with enhancements to future versions of the program. These enhancements vary greatly in their level of technical sophistication, but all are feasible with the proper computer programming skill sets. Developing the first version of the Estimating Tool in Microsoft Office Access ("Access") was done specifically to allow programmers visibility to the program source code for additions, deletions and modifications to the program logic for future releases.

The first limitation of the Estimating Tool is the need for users to enter a large quantity of information about a house including dimensions and material types for each room in the house that contains corrosive drywall. Although this information is necessary to compute an accurate estimate specific to a single house, it does take time for the user to compile the needed data and then input it into the program. As such, any interface changes to reduce this effort would improve the time needed to complete an estimate. One approach would be to add functionality to the Estimating Tool that would allow the user to duplicate information already entered into the program. For example, if a home were to contain a living room and a dining room with similar sizes and attributes, it would benefit the user to enter information about only one of these rooms and then simply click a button to duplicate the information for the second room. If this is done, the user would only need to make modifications for the second room rather than enter all the required fields a second time.

A second limitation of the Estimating Tool is the fact that construction cost data changes over time. The accuracy of any estimate is only as good as the square foot construction costs in the database. Updating this information requires either the user or a program administrator to have access to construction cost data and perform the needed updates as these values change. Creating a direct link between the Estimating Tool and the source of the construction cost data (such as R.S. Means) could eliminate this administrative burden. Rather than maintaining the cost data in each copy of the program, the information should be updated directly from the source of the cost data.

The third limitation of the program concerns the specific features of walls in a house and the capability of the Estimating Tool to capture this information for the total remediation cost. For example, many houses feature trim work to protect the wall and provide architectural features. The trim work often includes base molding, chair rail and crown molding. These are expensive features of the wall and may not be salvageable during the demolition phase of the remediation. Even if they are salvaged, they will need to be reconstructed and refinished during reconstruction. The Estimating Tool does not currently allow the user to capture information about theses features which could lead to an inaccurate cost of the total remediation. Future releases of the program should allow the user to capture more information about each wall such as the trim work, wallpaper, light boxes, ceramic tile and cabinetry that can not be salvaged.

A fourth limitation of the Estimating Tool is the platform on which the program was initially developed. Although Access provides the benefits of open source code, not all computer users have Access installed on their machines. If the Estimating Tool were moved to a Web-based platform, it would be more accessible to the general public. The ability to access the estimating program could also be limited to a specific set of login credentials established by the authority maintaining the website.

In summary, the Estimating Tool has the potential to provide the users a simpler, more accessible and more accurate means for creating a remediation estimate of a home containing corrosive drywall. However, these future enhancements will require additional time and skill to implement, and in all likelihood, will cost money. Until the changes are implemented, the first release of the Estimating Tool accurately provides users a ballpark estimate of a remediation effort based on the current inputs captured in the program.

APPENDIX A
REMEDIATION ESTIMATING TOOL FORMS

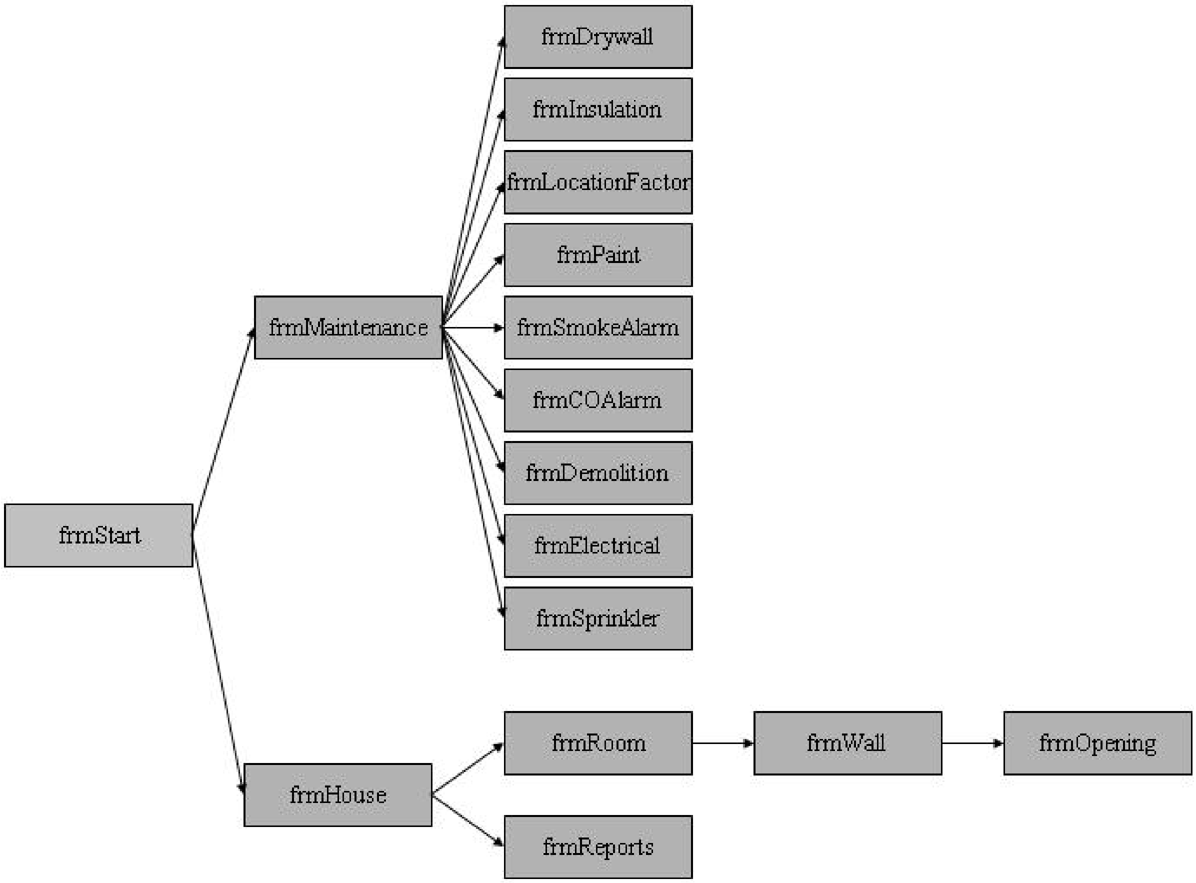

Figure A-1. Navigational relationship between forms in the Estimating Tool

Form Name	Table Name
frmCOAlarm	tblCOAlarm
frmDemolition	tblDemolition
frmDrywall	tblDrywall
frmElectrical	tblElectrical
frmHouse	tblHouse
frmInsulation	tblInsulation
frmLocationFactor	tblLocationFactor
frmMaintenance	N/A
frmOpening	tblOpening
frmPaint	tblPaint
frmReports	N/A
frmRoom	tblRoom
frmSmokeAlarm	tblSmokeAlarm
frmSprinkler	tblSprinkler
frmStart	N/A
frmWall	tblWall

Figure A-2. Record source of forms in the Estimating Tool

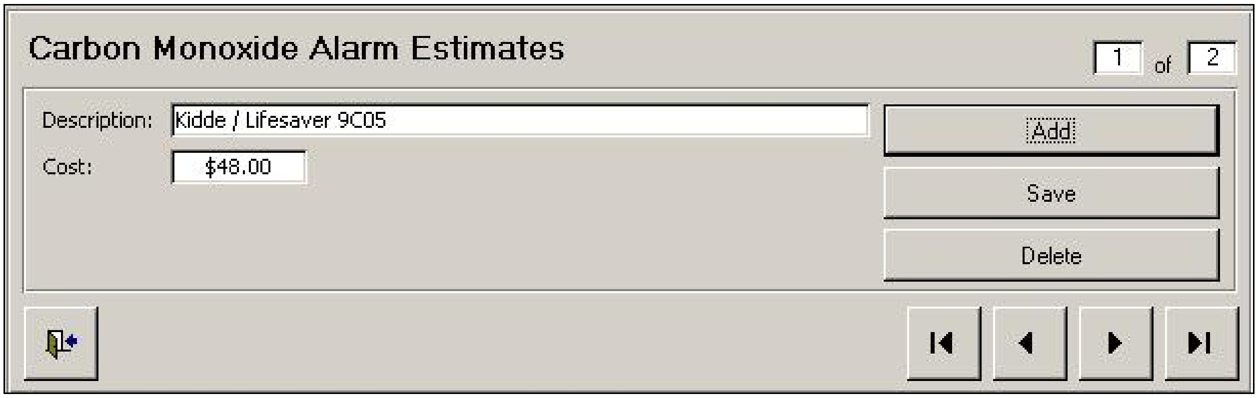

Figure A-3. GUI of frmCOAlarm from the Estimating Tool

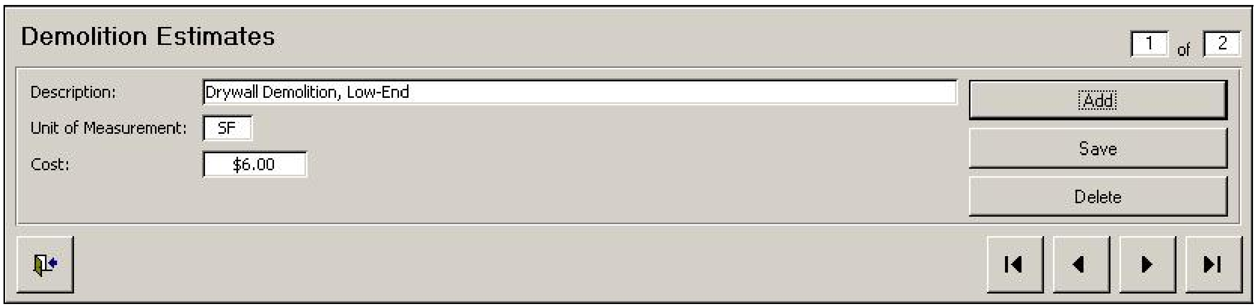

Figure A-4. GUI of frmDemolition from the Estimating Tool

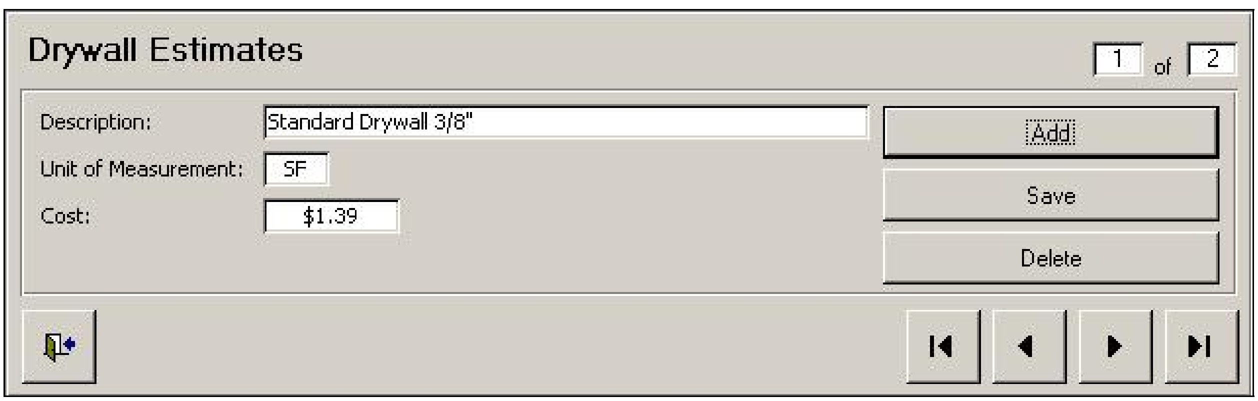

Figure A-5. GUI of frmDrywall from the Estimating Tool

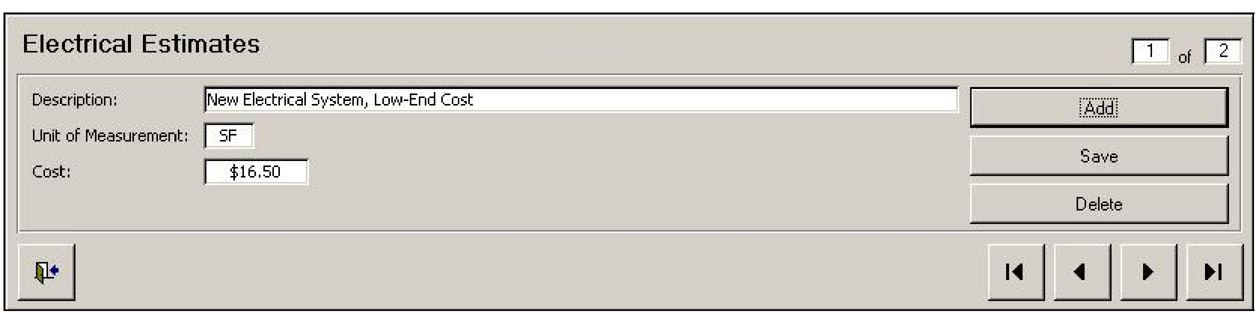

Figure A-6. GUI of frmElectrical from the Estimating Tool

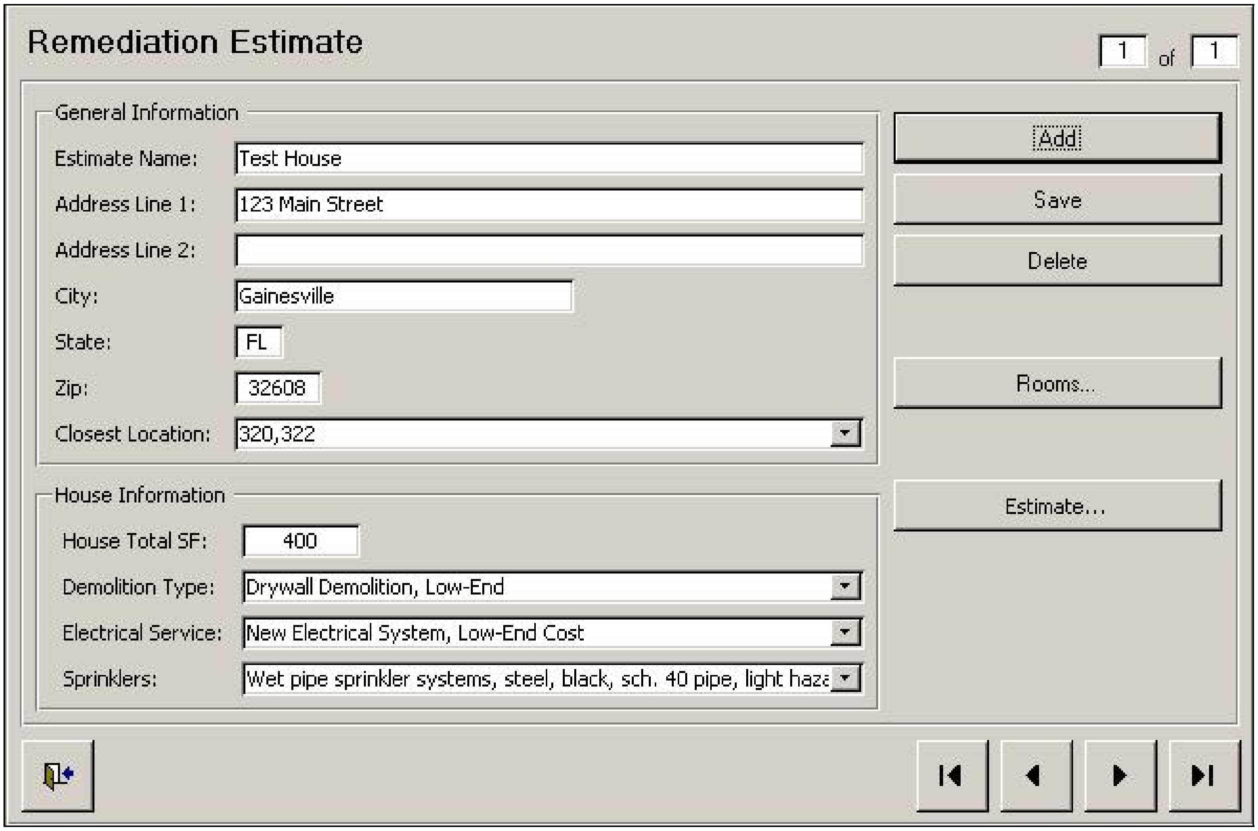

Figure A-7. GUI of frmHouse from the Estimating Tool

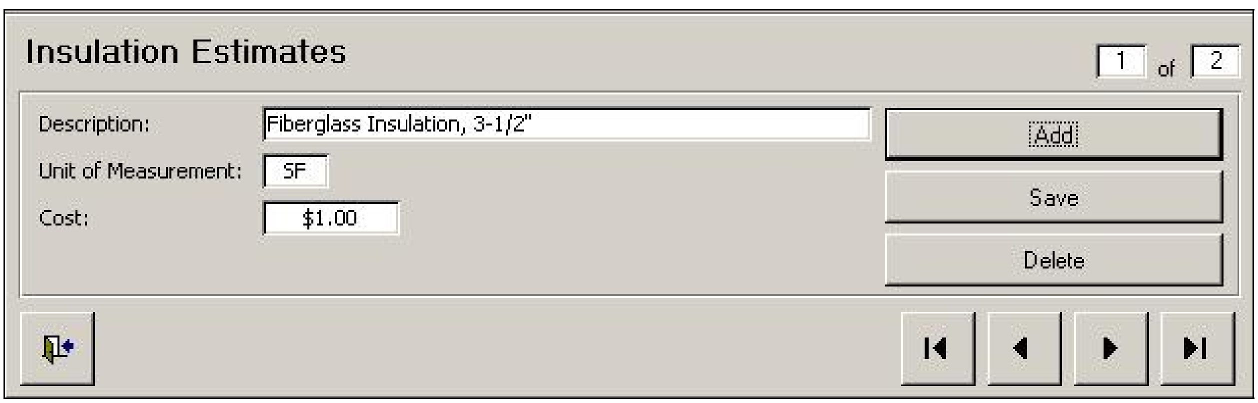

Figure A-8. GUI of frmInsulation from the Estimating Tool

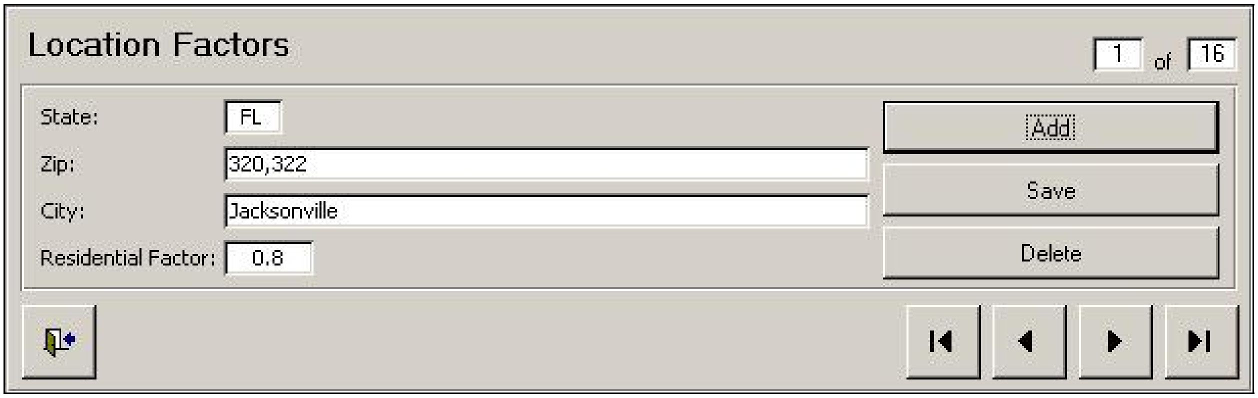

Figure A-9. GUI of frmLocationFactor from the Estimating Tool

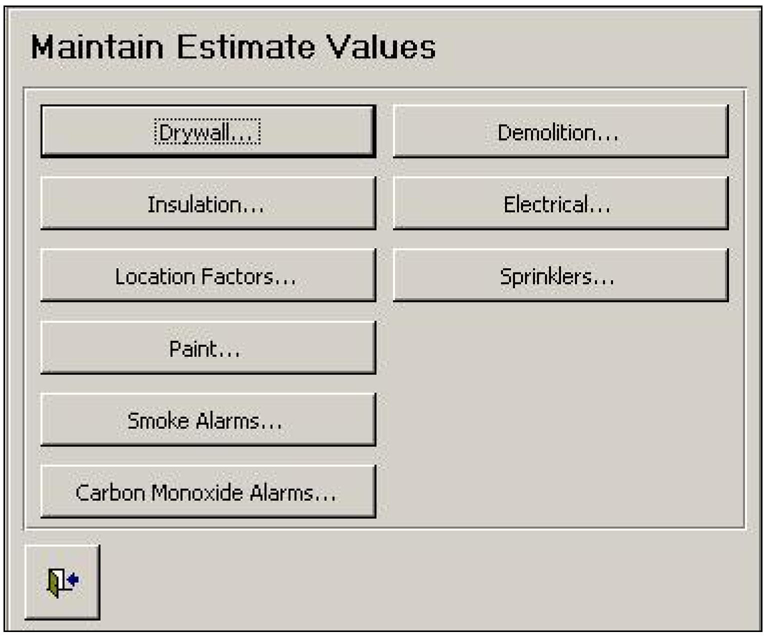

Figure A-10. GUI of frmMaintenance from the Estimating Tool

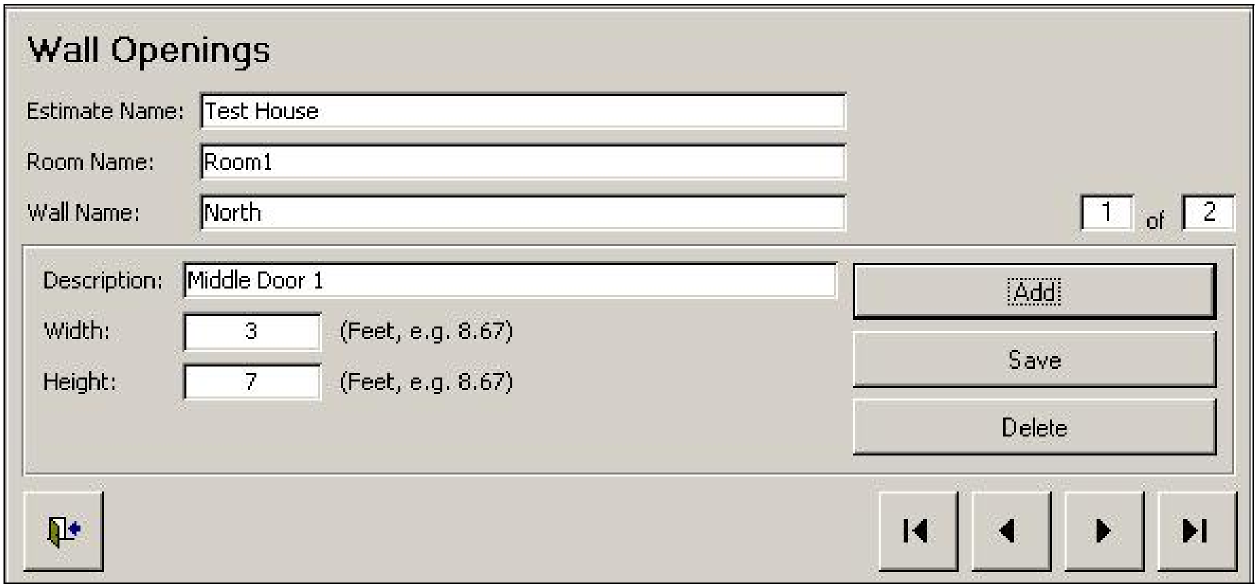

Figure A-11. GUI of frmOpenings from the Estimating Tool

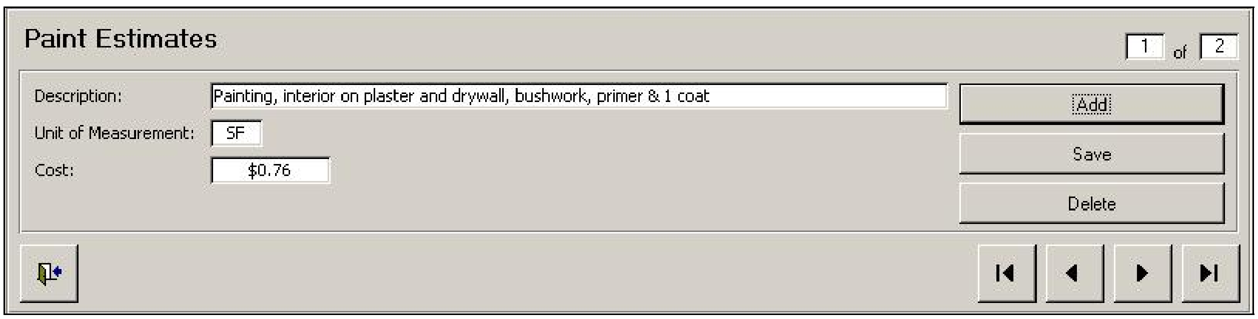

Figure A-12. GUI of frmPaint from the Estimating Tool

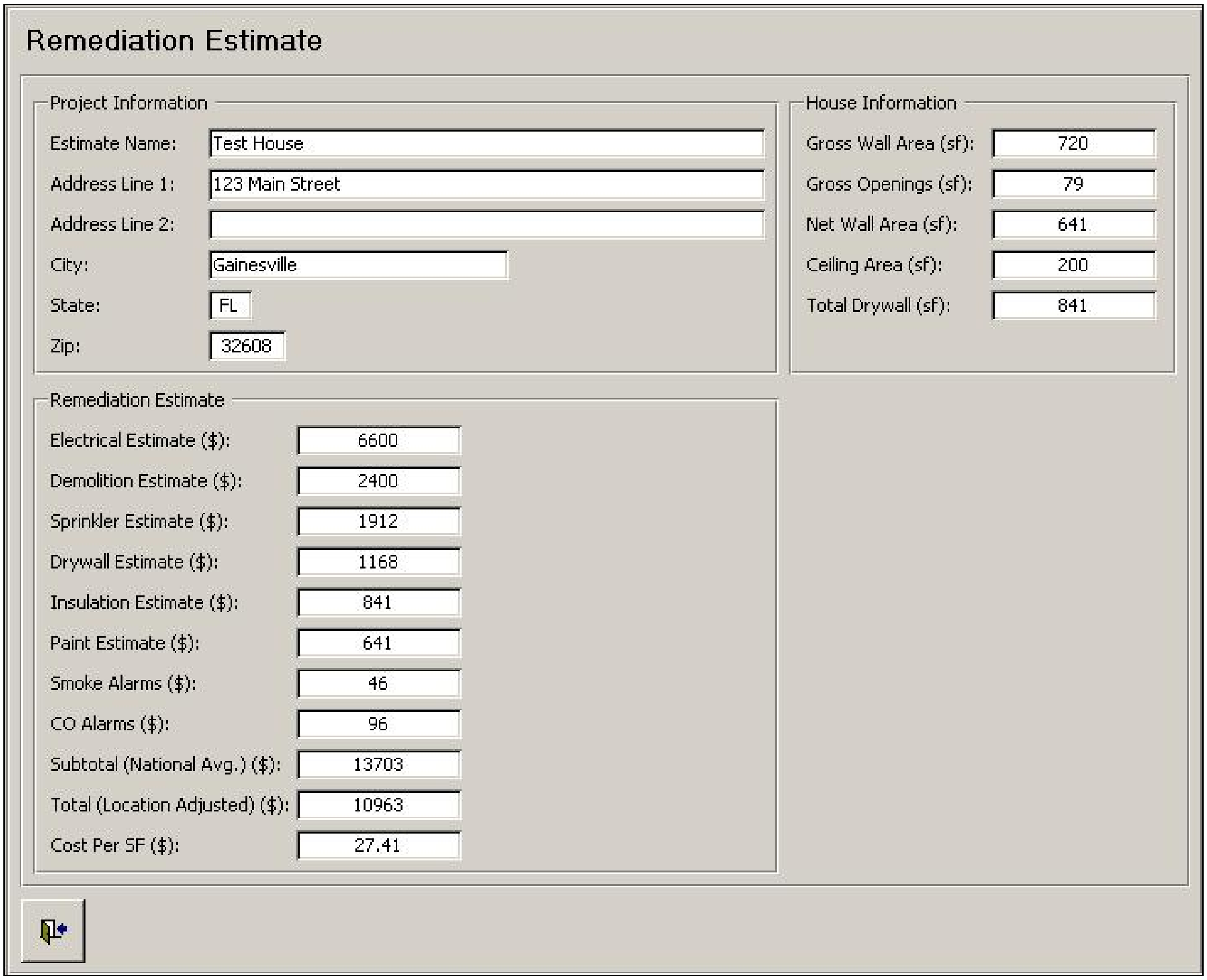

Figure A-13. GUI of frmReports from the Estimating Tool

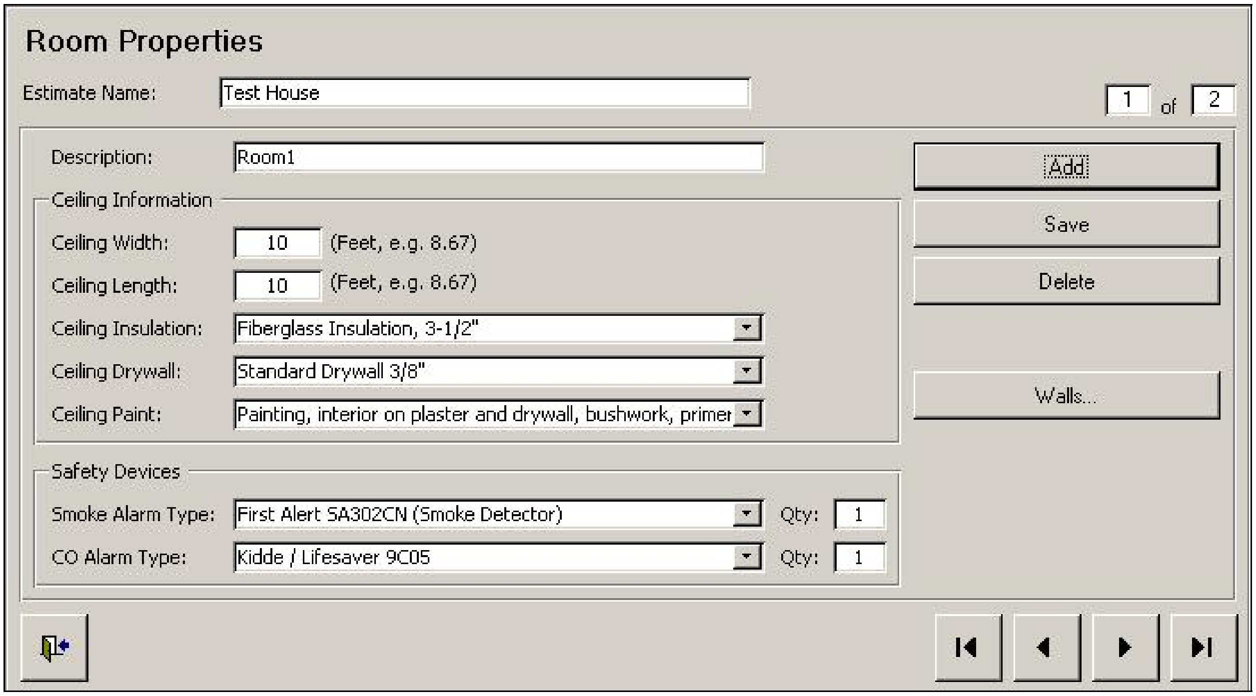

Figure A-14. GUI of frmRoom from the Estimating Tool

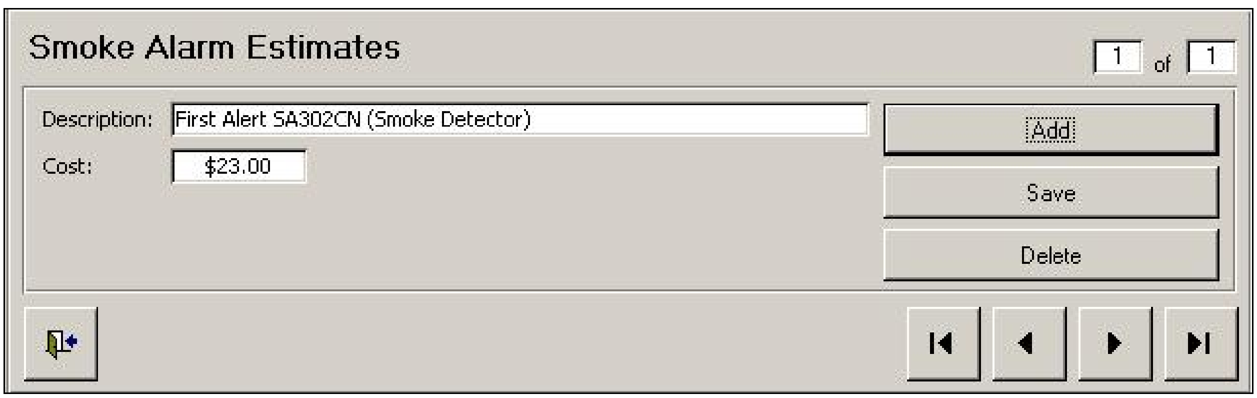

Figure A-15. GUI of frmSmokeAlarm from the Estimating Tool

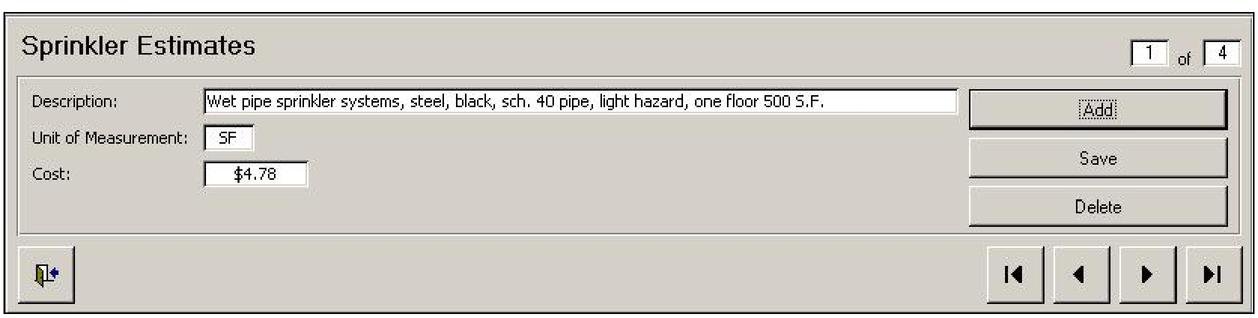

Figure A-16. GUI of frmSprinkler from the Estimating Tool

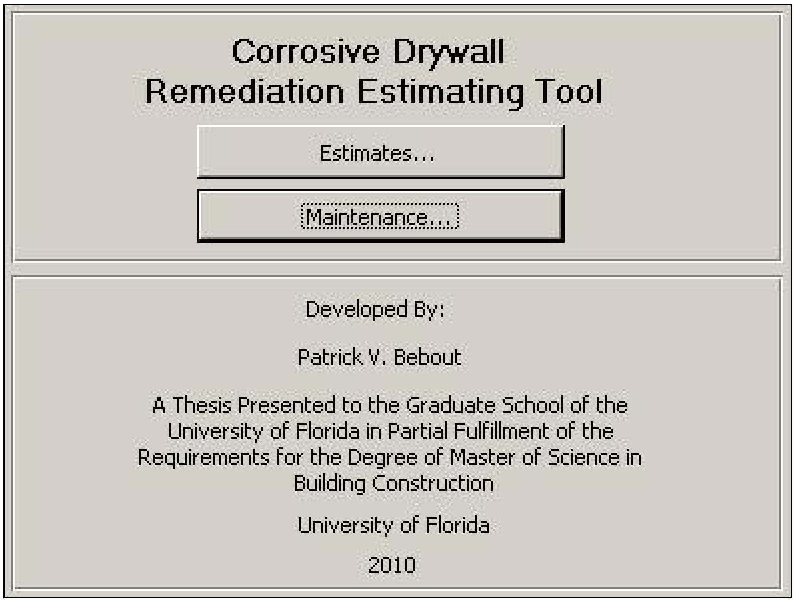

Figure A-17. GUI of frmStart from the Estimating Tool

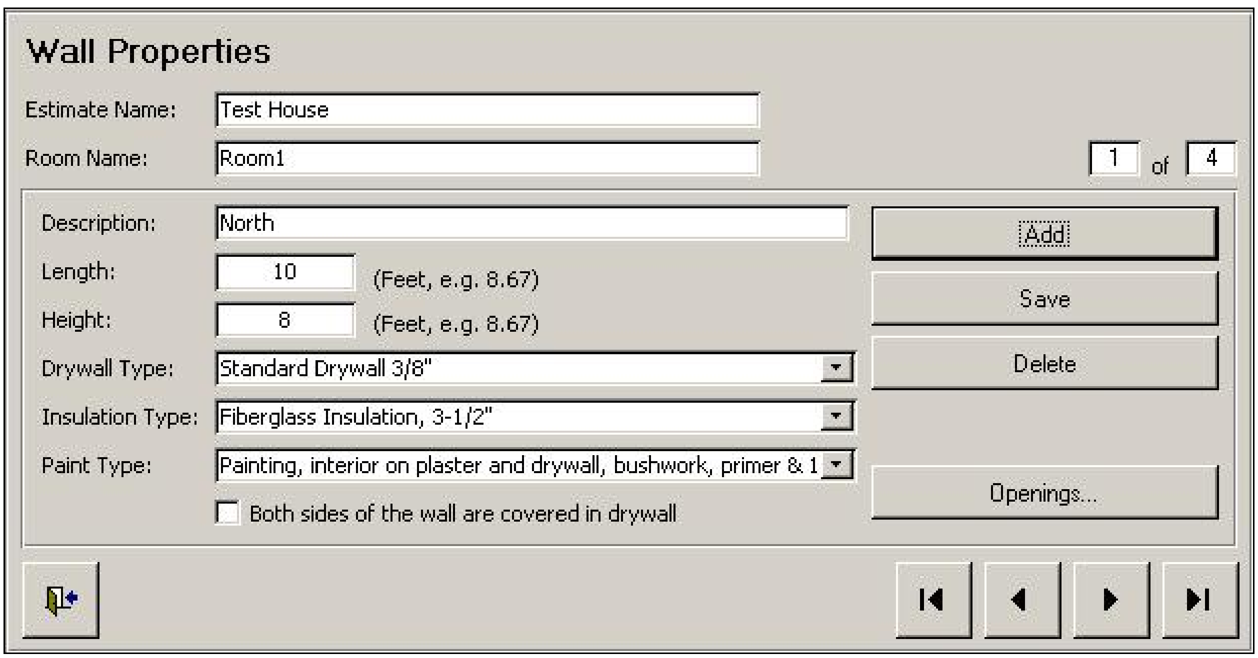

Figure A-18. GUI of frmWall from the Estimating Tool

APPENDIX B
REMEDIATION ESTIMATING TOOL DATABASE

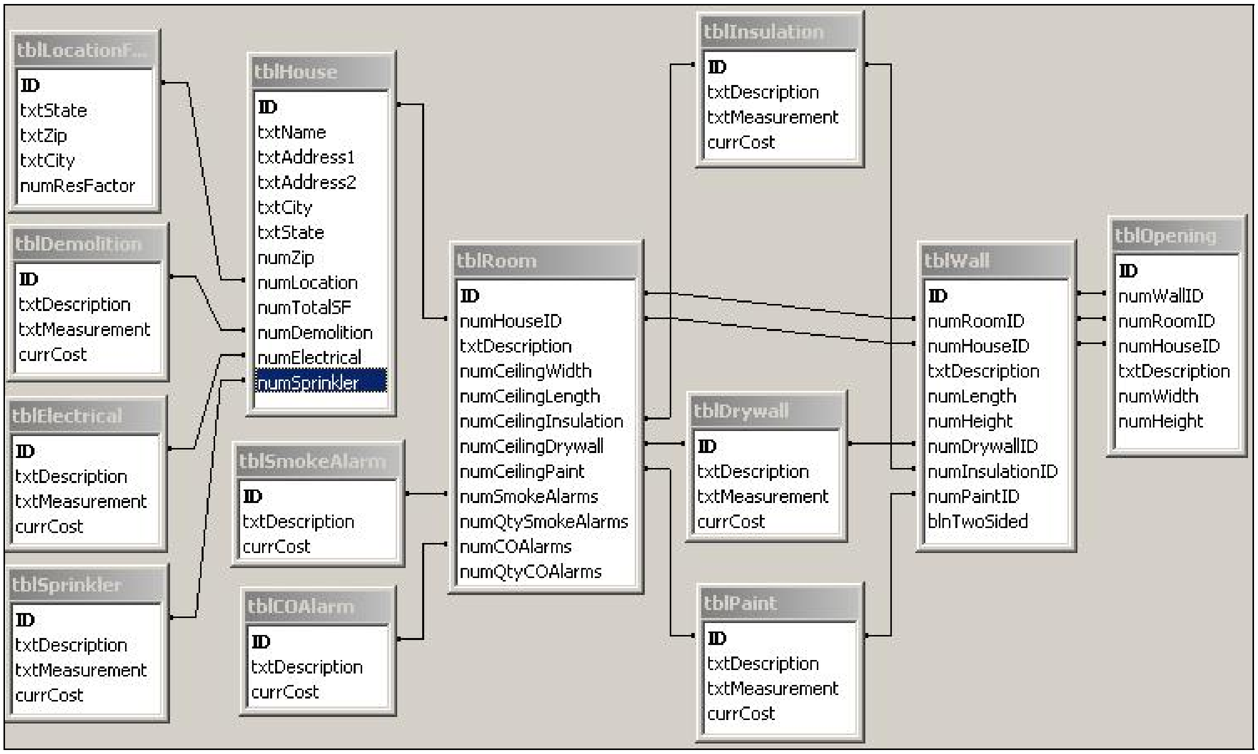

Figure B-1. Relationship of database tables from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblCOAlarm	ID	AutoNumber	Yes
	txtDescription	Text	No
	currCost	Currency	No

Figure B-2. Design of database table tblCOAlarm from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblDemolition	ID	AutoNumber	Yes
	txtDescription	Text	No
	txtMeasurement	Text	No
	currCost	Currency	No

Figure B-3. Design of database table tblDemolition from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblDrywall	ID	AutoNumber	Yes
	txtDescription	Text	No
	txtMeasurement	Text	No
	currCost	Currency	No

Figure B-4. Design of database table tblDrywall from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblElectrical	ID	AutoNumber	Yes
	txtDescription	Text	No
	txtMeasurement	Text	No
	currCost	Currency	No

Figure B-5. Design of database table tblElectrical from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblHouse	ID	AutoNumber	Yes
	txtName	Text	No
	txtAddress1	Text	No
	txtAddress2	Text	No
	txtCity	Text	No
	txtState	Text	No
	numZip	Number	No
	numLocation	Number	No
	numTotalSF	Number	No
	numDemolition	Number	No
	numElectrical	Number	No
	numSprinkler	Number	No

Figure B-6. Design of database table tblHouse from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblInsulation	ID	AutoNumber	Yes
	txtDescription	Text	No
	txtMeasurement	Text	No
	currCost	Currency	No

Figure B-7. Design of database table tblInsulation from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblLocationFactor	ID	AutoNumber	Yes
	txtState	Text	No
	txtZip	Text	No
	txtCity	Text	No
	numResFactor	Number	No

Figure B-8. Design of database table tblLocationFactor from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblOpening	ID	AutoNumber	Yes
	numWallID	Number	No
	numRoomID	Number	No
	numHouseID	Number	No
	txtDescription	Text	No
	numWidth	Number	No
	numHeight	Number	No

Figure B-9. Design of database table tblOpening from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblPaint	ID	AutoNumber	Yes
	txtDescription	Text	No
	txtMeasurement	Text	No
	currCost	Currency	No

Figure B-10. Design of database table tblPaint from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblRoom	ID	AutoNumber	Yes
	numHouseID	Number	No
	txtDescription	Text	No
	numCeilingWidth	Number	No
	numCeilingLength	Number	No
	numCeilingInsulation	Number	No
	numCeilingDrywall	Number	No
	numCeilingPaint	Number	No
	numSmokeAlarms	Number	No
	numQtySmokeAlarms	Number	No
	numCOAlarms	Number	No
	numQtyCOAlarms	Number	No

Figure B-11. Design of database table tblRoom from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblSmokeAlarm	ID	AutoNumber	Yes
	txtDescription	Text	No
	currCost	Currency	No

Figure B-12. Design of database table tblSmokeAlarm from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblSprinkler	ID	AutoNumber	Yes
	txtDescription	Text	No
	txtMeasurement	Text	No
	currCost	Currency	No

Figure B-13. Design of database table tblSprinkler from the Estimating Tool

Table Name	Field Name	Data Type	Primary Key
tblWall	ID	AutoNumber	Yes
	numRoomID	Number	No
	numHouseID	Number	No
	txtDescription	Text	No
	numLength	Number	No
	numHeight	Number	No
	numDrywallID	Number	No
	numInsulationID	Number	No
	numPaintID	Number	No
	blnTwoSided	Yes/No	No

Figure B-14. Design of database table tblWall from the Estimating Tool

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BIOGRAPHICAL SKETCH

Patrick Vernon Bebout was born in State College, Pennsylvania to John and Ann Bebout. He has a younger brother, Andrew, and a younger sister, Nicole. He graduated from high school in June of 1994 and started his college career one year later at the University of Virginia in Charlottesville, Virginia. He graduated with a bachelor of science in commerce in May of 1999. After graduation, he began work as an analyst for an information technology consulting firm. After several years, he switched careers to begin work as a project manager for a large homebuilder in Virginia. In 2008, he was accepted by the University of Florida to pursue a Master of Science in Building Construction. After graduation, Patrick plans to resume his career in construction.