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# Hazard Perception and Lifesafety Analysis

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by

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## Abstract

People live in the presence of hazards every day. The recognition of hazards and the perception of their importance is a result of behavioral tendencies and acquired knowledge. Many true hazards go unnoticed, while other situations are labeled falsely as hazards. This project attempted to assess the perception of lay persons to potential hazards within the built environment and to compare the findings with those of building inspectors.

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## 1. Human Behavior

Fire would be a much easier force to control or prevent if the only factors governing it were the materials within a building and the building's built-in automatic defenses. However, human behavior, in many cases, effects the outcome of a fire situation to a much greater degree than does the structure the fire ignites in. Looking back through history, very few significant fires, conflagrations that resulted in notable loss of life or damage to structures, took place in buildings characterized by low income levels, highly primitive materials, or poor living conditions. Rapid urbanization or limited planning can likewise not be blamed for these disasters in the same way they were blamed for the huge city fires of New York, Atlanta, and Chicago, among many others. Cities and towns are now substantially organized when it comes to fire departments and fire protection agencies. If a fire occurs and is properly reported, it will be extinguished. There is no doubt about that. The doubt arises when one factors in the requirements of people to recognize a hazardous fire situation, report it, and bring themselves and their co-inhabitants to a safe location away from the hazard.

Fire kills far fewer people than does war, or automobile accidents, or even accidents in the home. However, a fire is a very noticeable disaster. A misplaced, lit match has the potential to take a family's home away from them. Large fires at public gathering areas, such as sports stadiums, office buildings, or hotels often scare the public into staying home. Likewise, they often lead to an increased feeling of need for better standards in terms of the design of buildings (taking into account such things as egress routes and detection and suppression systems). A fire that results in the loss of a person's life rarely avoids mention in a newspaper. Many people read of such incidents and think that there is a need for better response and extinguishment methods, but the persons responsible for these actions are the ones involved in the situation who are most highly trained and know exactly what to do. It is the often the occupants of the building who perform incorrectly or inappropriately, due mainly to lack of familiarity with detection, notification, and evacuation procedures. Engineering and technology cannot wholly solve the world's fire problems.

With the current level of fire protection technology and fire management policies, it is clear that the role of human error plays a large part in fire disasters. In November, 1988, thirty-one people were killed by a fire in Kings Cross Underground Station in Great Britain.[1] The fire never developed into a major incident within itself, and in its early stages could have very easily been extinguished with readily available fire extinguishers. However, inappropriate human reactions involving the incorrect recognition of the severity of the situation and the poor control of the people in the station led to a disaster. If one cannot directly blame most major fires on human error, one can say that most fires that escalated to disaster status did so because people did not react properly to the initial threat. It should be noted that few domestic fires are labeled "disastrous," even though they contribute greatly to the fire death statistics. The same types of human errors that contribute to large-scale fires also often contribute to small domestic fires, however these errors are more often directly and fully linked to the fire severity than is building engineering, which plays a larger role in large buildings.

Human behavior in fires is not an easy phenomenon to study. The causes of this behavior are fortunately very rare, and studies cannot be arranged ahead of time. People's instant, "gut" reactions in a fire situation are most important, and the stress involved in such a situation cannot be accurately simulated in safe conditions. Likewise, people who have been in a fire often do not remember what they did at the time, often because their gut reactions, whether appropriate or in error, required no substantial thought. Often, people who have been through a fire are too emotionally scarred to talk about the experience in depth, so details of their behavior are not available. Obviously, people who perish in a fire cannot directly contribute to one's knowledge of people's behavior in hazardous situations, although forensic science does allow for a deceased person's actions prior to their death in order to piece together the set of actions that person took when faced with the hazard. Nonetheless, it is clear that this in not conventional research into human behavior.

A word which seems to have become synonymous with human behavior in fire situations is "panic." The concept of panic is very important, and plays a large role in fire regulations, evacuation procedures, and building design. It is also a term that the media loves. Few news reports on fires that occur in inhabited structures do not include the word panic, mainly because it is assumed that people grow intensely scared when faced with smoke or flames. People may panic when thinking ahead to the possibility of being trapped in a burning building, or even after having escaped from such a situation and realizing how much danger they were in, but often, in the process of detection, notification, and evacuation, people do not panic to extreme degrees. There are, of course, exceptions to this statement. If a person is faced with a hazardous situation and has no idea where the nearest exit is, feels alone or lost, or begins to feel the effects of heat and smoke, then that person will likely panic. The energy which would normally be devoted to evacuation is displaced to thought and panic when evacuation is seemingly impossible.

On April 12, 1973, about 3000 teenagers were attending a concert in Munich.[2] There was no fire or emergency situation, and the teens were not evacuating, but simply leaving the building after the conclusion of the performance. Two girls were crushed to death, and a number of other people were injured. Subsequent investigation revealed that the eight other exits in the building were hardly used, because the people did not realize they were there. The people towards the back of the exiting crowd did not realize how much pressure was being exerted on those in the front, who were attempting to exit through the limited door space. If a fire had occurred in the building while it was full, the evacuation would have been disastrous. The people inside were not familiar with the exits or the layout of the building, and most likely would have panicked when they realized that the crowd was not moving out of the building quickly. This is a situation where panic would have played a huge role.

For situations where fewer people are located in one place, such as office buildings that are more spread out, or even domestic residences, panic plays less of a role. People are able to put energy into finding a way to escape. Office or family escape plans, mapped out before the occurrence of an actual hazardous situation, greatly reduce the level of panic experienced by people because they know what they should do to escape, and do not have to stop to consider their options. It can be generalized that panic occurs when there are excessive distances to be traveled, limited access to exits, few or small exits, widely separated or inconveniently spaced stairs, or when the person is largely unfamiliar with the building. Clearly, many of these factors can be controlled in the building design process. For instance, if one was to hear fire alarms sounding and step out of an office into the hallway shown on the following page, one might be very confused as to where to go to find an exit, since none are clearly posted. This might lead to panic.

Figure 1.1. Example hallway.

Panic is often associated with a response to fear resulting in flight. However, it is often believed that this flight is not under the control of reason or sensible thought, but rather a disorganized attempt to flee ruled by an emotional state. Granted, flight is not the way people normally leave a building, but it very rarely results in an animalistic, non-rational desperation to find an exit, unless the person is totally lost within the space and no exits are within sight range. Panicked flight can be avoided by clearly labeling exits or by setting up evacuation procedures prior to the occurrence of hazardous situations. Note the office setup shown below. Someone working at the highlighted cubicle clearly has a certain escape route, but if the person has not been informed of the necessary egress path, or did not carefully note it on the way to the cubicle, then he might wander from one confined cubicle to another, unable to find the way out of the office.

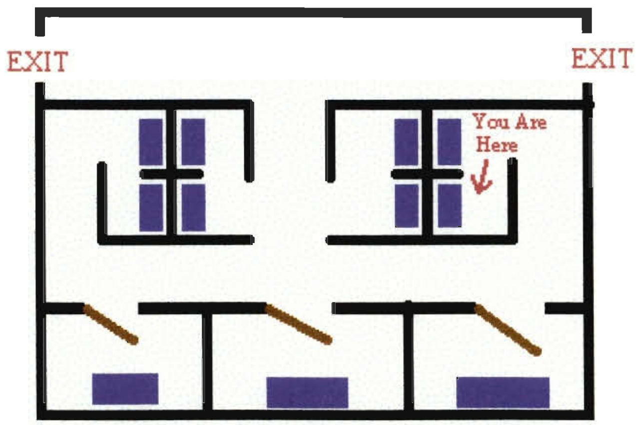



Figure 1.2. Example office layout.

It is common in a large-building fire for people to form groups when trying to escape. This can be both beneficial and harmful. If someone who knows the layout of the building takes charge of the group, then many lives can be saved quickly and efficiently. If the person who is assumed to be the leader is lost, panics, or behaves in a way which seems rational to him but is non-adaptive for the group as a whole, disaster may occur. In a psychological experiment by Mintz in 1951,[3] it was found that a cooperative group, rather than a competitive one, was able to accomplish a task, such as exiting a building, with much less hassle and aggravation. This makes much sense, but might not occur to someone in a hazardous situation. Often, panicked pushing or trampling results when a member or members of a group feel the progress of the group is counterproductive. This is hard to avoid, but as mentioned before, clearly marked escape routes and pre-planned evacuation procedures can greatly increase the chances that a large group of people will escape safely together.

People have several different roles in fires. First of all, people can cause fires. Human negligence is a very common cause of fires. A carelessly discarded piece of smoking material or a pile oily rags can lead to an ignition and an eventual working fire. Such a situation can easily be avoided through common sense or increased safety training, but it is still a usual occurrence. Until very recently, the focus was placed more on engineering considerations to prevent fires, and human errors were overshadowed and labeled as wholly accidental, and therefore uncontrollable. However, it is becoming more apparent that management and training are very important tools in fire prevention. Teaching safe material handling and working practices, as well appropriate procedures to deal with accidents can go very far towards preventing disasters.

On the other hand, a fire that is started by a human is not necessarily accidental. Arson, in its many forms, is something that cannot be prevented by training. Setting fires for profit, or for some type of entertainment based on a fascination, in the case of adolescents, is a very significant cause of fire. This behavior cannot necessarily be directly controlled, but points towards to importance of education, both in school and within the family structure. Knowledge of fire can go a long way towards preventing hazardous situations.

Regardless of the source, once a fire has started, the outcome of the situation generally depends on the reactions of the people involved. Possibly the most important human factor is recognition. Someone must realize that there is a fire, and that the situation is potentially hazardous, before any other actions can be taken to protect the building and its occupants. Unless a building is extensively equipped with automatic detection and suppression systems, and the fire department can be on scene exceptionally fast, no fire suppression efforts can be put into action unless someone identifies the hazard and recognizes the need to seek assistance to deal with it. The early stages or recognition are often characterized by ambiguity. A person's actions might be delayed to a dangerous extent simply because he does not understand exactly what is going on or what he should be doing. Some light smoke trickling out from under a door might not get immediate attention, and when it does, it will most likely be investigated by whomever discovers it before that person takes the responsibility to report it.

There are several factors that control a person's actions immediately after a fire is discovered and deemed dangerous. Most people will realize that they need to notify other occupants of the fire building of the presence of the fire. This might be an easy task, as in the case of a small, single family house, or very difficult, in the case of a high-rise office building. In any case, the notification process is greatly simplified by the presence of manual-pull fire alarms, but a person must choose to pull the alarm for it to be effective. It should not be assume that there is a single, specific behavioral routine that should be followed in the case of any fire. Buildings vary to such a great degree that the only effective way for a person to know what to do in the case of a fire is to pay attention to fire warning notices and notification/evacuation systems when working or living within a given building. In some instances, the best course of action may be to warn others, while in other situations, it might be best to try to cope with the fire with manual defense mechanisms such as fire extinguishers or other tools.

Based on many studies, it appears that, when faced with a fire, most people will actually not panic. Instead, they will tend to carry out their normal roles. The organizational characteristics of the building occupants generally remain intact during a fire situation. An excellent example of this occurred in 1977 at the Beverly Hills Supper Club in Kentucky.[4] During the fire, waiters and waitresses showed people out of the building. However, it seems that each waiter or waitress only helped the people who were seated at the tables he or she was responsible for during normal operation. 164 people died in this fire, and many of them were seated at tables directly adjacent to people who were successfully rescued by their own waiters or waitresses. Similarly, husband and wife roles are almost always maintained during a fire.

Once the fire has been recognized and people have been notified of its presence, activity assumes a single focus: escape. A review of most fire regulations will show that most deal to a great extent with providing a means of escape without hindrance or exposure to further hazards. An effective fire exit path should allow the inhabitants of a building to escape on their own without assistance or undue delay or hazard. These regulations, however, do not guarantee safe egress from a burning building. This is clear in the case of large office buildings or stadia, which are designed to hold a large amount of people in normal conditions. The design fails when all of these people need to exit as quickly as possible. Bottlenecking can occur and prevent other people from escaping. Also, the potential for stair accidents is increased when many people are hurrying out of a building. Either of these situations can lead to deadly consequences. Sometimes it is actually safer to keep people in safe areas of very large buildings, and defend them in place, if structural stability allows.

Peter Wood of the University of Surrey conducted an interesting survey in the early 90's.[5] Data was collected from nearly 1000 fire incidents, and nearly 2000 victims were interviewed. The survey focused on the behavior of the people, as well as their evacuation methods, especially through smoke. About 50% of the incidents occurred in residential homes, 17% in factories, 11% in apartment complexes, 7% in stores, and 4% in institutions such as hospitals or schools. The results of different aspects of the survey are given on the following page.

The behavior of the people in the incidents can be categorized into three general types of reactions. These are, in order of frequency,

1) Concern wit evacuation of the building either by oneself or with others.
2) Concern with fire-fighting or at least containing the fire.
3) Concern with warning or alerting others, either individuals or the fire department.

The following is a summary of people's first actions in the fire incidents.

| Behavior Category | Percentage of participants undertaking this as their first activity |
|---|---|
| 1. Take some firefighting action. | 15 |
| 2. Contact fire department. | 13 |
| 3. Investigate fire. | 12 |
| 4. Warn others. | 11 |
| 5. Do something to minimize danger. | 12 |
| 6. Evacuate oneself from building. | 9.5 |
| 7. Evacuate others from building. | 7 |

Table 2.1. First actions in a fire situation.

The variables which led to increased evacuation of the buildings were, in descending order of importance,

1) Extensive smoke spread as opposed to less extensive.
2) Home environment as opposed to work environment.
3) Lack of previous involvement in a fire as opposed to previous experience.
4) Women as opposed to men.
5) Younger people as opposed to older people
6) Untrained people as opposed to trained people.
7) People familiar with the building as opposed to those who were not familiar.
8) The presence of smoke as opposed to the absence of smoke.

The factors influencing people's movement through smoke are summarized below.

| Influence factors | | Percentage of people willing to move through smoke. |
|---|---|---|
| Sex | Men | 64 |
| | Women | 54 |
| Smoke spread | Extensive | 64 |
| | Less extensive | 33 |
| Environment | Home | 64 |
| | Work | 52 |
| Time | Day | 65 |
| | Night | 56 |
| Building familiarity | Completely familiar | 61 |
| | Not so familiar | 51 |

Table 2.2. Factors influencing people movement.

While this study could not result in a definite, across the board conclusion regarding people's behavior in fires, it can show some definite trends. For instance, such factors as extensive, dense smoke spread, familiarity with the building, lack of training, age, and even sex all appear to greatly effect a person's behavior in a fire situation. If there is dense smoke present, or if a person is highly unfamiliar with the building or untrained in fire safety, then there is a much higher risk of casualty. It was also found that in incidents involving casualties, a much smaller percentage of people contacted the fire department after the fire had been detected, while a larger percentage investigated the fire, warned others, tried to save personal effects, and moved towards exits. Clearly, this shows that the best first response in most situations is to notify the fire department, if it is immediately safe to do so. Also, it is clear that it is very important to have notification and evacuation procedures set up ahead of time, so that in the event of a fire, the appropriate tasks get accomplished and the individuals involved have the greatest chance to exit the hazard area.

Notes

[1]Canter, David, ed., *Fires and Human Behavior,* (London: David Fulton Publishers, 1990). 1.

[2]Canter, *Fires and Human Behavior.* 64.

[3]Mintz, A. "Nonadaptive Group Behavior" *Journal Abnormal and Social Psychology*, 1951. 46.

[4]Best, R. L. *Investigation Report: The Beverly Hills Supper Club Fire, Southgate, Kentucky, May 28, 1977.* (NFPA, 1977).

[5]Canter, *Fires and Human Behavior.* 83.

## 2. Materials

One of the most important factors governing a person's perception of hazard within a space when there is not actually a fire situation present is the presence of different materials. Many people have views of different types of materials as being highly flammable, or conversely, highly safe. The survey included in this report will attempt to identify different perceptions people have, including perceptions regarding materials. However, it is important to identify the true nature of hazard imposed by different types of materials. By doing this, one will be able to determine if people's views of the hazard levels of different materials are justified.

### 2.1. Structural Materials

For effective fire protection, the structural elements of a building must be able to support the loads imposed on the structure under the harsh conditions of a fire. Also, the structure should be able to contain or limit the spread of smoke and fire gases, as well as flames. No material will perform these tasks beyond a certain duration, and all will fail eventually. However, a building that can be considered successful in a fire will have a structure that supports its loads and contains the fire and its elements long enough to allow the occupants to evacuate and the fire department to safely enter the building and extinguish the fire. If portions of the structure fail, it could collapse, and people, both occupants and firefighters, can be severely injured or killed.

Steel is a very common structural material in large buildings such as offices and institutions. It is very strong, and tends to perform well in average sized fires. However, above 400 to $500^0$ F the ultimate tensile strength of steel begins to decrease. As temperatures continue to increase, the tensile strength drops rapidly, as shown in the curve below.[1] This means that those members in tension within a structure will begin to fail as high temperatures are reached. The data in the graph represent the lowest strengths during ½ to 10 hours exposure under no load. Obviously, steel within a building is under load, and thus may perform differently. Still, this data gives a good indication of the behavior of tensile steel in a fire.

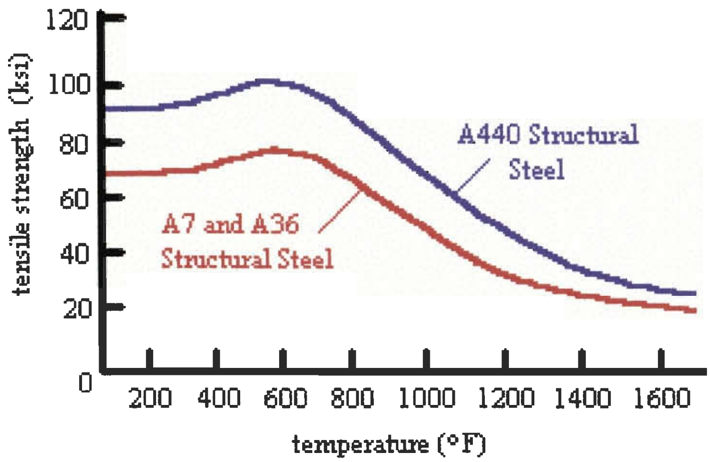



Figure 2.1.1. Tensile strength verses temperature for steel.

Similarly, above 200 to $400^0$ F, the compressive strength of steel begins to decrease rapidly. Above 800 to $900^0$ F, steel beams loaded in compression, such as columns, can buckle outward, causing the structure to fail. The change in compressive strength based on temperature changes is shown in the graph below.[2]

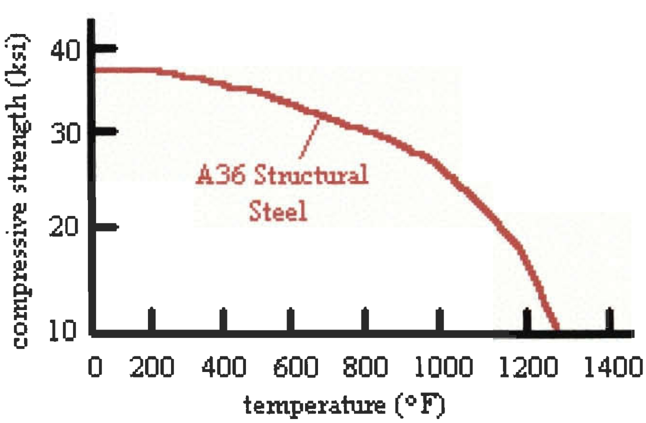



Figure 2.1.2. Compressive strength verses temperature for steel.

There are several ways that steel columns and beams can be protected during a fire. Generally, the most effective method is the encasing of the member within several layers of gypsum board. A steel I-beam enclosed within two layers of 5/8" gypsum board, as shown in the figure below, can achieve a fire rating of up to four hours.[3] Alternately, there are spray-on products available which can give a fire rating of two to four hours,[4] depending on the final thickness of the coating. These coatings require strict application procedures, however, and are often not particularly durable during construction. An unprotected steel member can have a rating of up to one hour[5] provided its mass is large enough. This is often not practical in terms of cost and constructability, however.

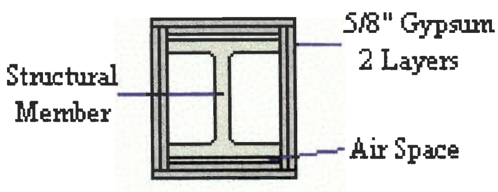



Figure 2.1.3. Protected steel member.

Concrete is also affected by fire. Above 600 to 700$^0$ F, the compressive strength of concrete begins to decrease considerably. The graph on the following page shows the strength verses temperature characteristics of a four-inch diameter concrete test sample loaded in compression.[6] It should be noted that, generally, conventional structural concrete members have enough mass to replenish some surface moisture dissipated by fire and to absorb excess surface heat. Thus, actual structural members may perform slightly better than the data on the following page implies.

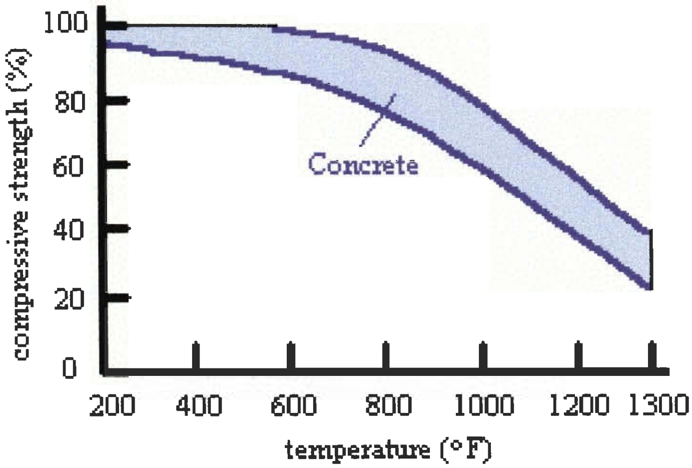


Figure 2.1.4. Compressive strength verses temperature for concrete.

Concrete is not generally used in structures to handle tensile forces, due to the fact that it has very minimal tensile strength. However, to handle tensile forces that may be present, steel reinforcing bars are incorporated into concrete members. This steel performs similarly to the tensile steel discussed previously, however, a layer of concrete, which absorbs heat and retains moisture, protects it. Thus, the reinforcing steel is not directly subjected to the effects of fire, and will not fail as quickly as will an exposed steel member.

In residential applications, wood is by far the most common structural material. Unprotected structural wood performs poorly in a fire unless they are of substantial mass. In a fire, wood is consumed, and charcoal is produced, at a rate of about 1/40 inches per minute.[7] if the wood member has sufficient mass, this charcoal can act as a protective coating, and the member can maintain its strength for a relatively long time. Wood construction is generally covered with gypsum board or a similar material, which offers an acceptable fire rating. A load-bearing wall constructed with 2x4 or 2x6 wood studs, covered with ½" thick gypsum, and insulated with fiberglass batting can have a fire resistance rating of over one hour,[8] which is acceptable in residential applications. It should be noted that the fire rating does not mean that the rated material is noncombustible, but rather that the material will not be penetrated by fire within the rating time, based on ASTM standard time-temperature exposure. The fire might penetrate *into* the assembly, but it will not penetrate through it in the rating time.

Wood floor/ceiling assemblies with plywood floor decks and gypsum or acoustical ceiling panels generally have one-hour fire ratings, similar to wall assemblies. However, bare wood floors with exposed joints typically fail in less than 15 minutes when exposed to ASTM standard time-temperature curve conditions.[9] This failure allows fire to penetrate into the floor/ceiling support structure quickly, and the overall rating of the assembly is thus negatively affected.

In wood construction, it is very important to include fire stops in the walls between floors. This will help prevent the spaces in between wall studs from assuming a role similar to a chimney. The concealed flu will allow fire to travel within walls between floors unless there is some sort of barrier included within the walls. This can be as simple as a wood stiffener equal in thickness to the studs used to form the wall. Also, fiberglass batting or blown-in insulation can serve the same purpose, assuming the material is fire-resistant. Examples of acceptable fire stops are shown below.

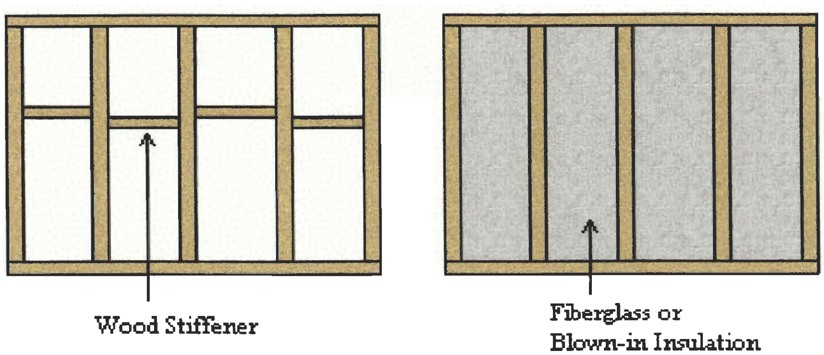


Figure 2.1.5. Fire stops in walls.

It is also very important to insure that all penetrations in walls, floors, or ceilings are either of a minimum required size, based on the size of the object that must pass through the barrier, or properly sealed. An open penetration can decrease the fire rating of a floor/ceiling assembly drastically. A pipe penetrating three or more floors should be enclosed in a shaft in order to lessen the chance of fire spread between multiple floors.[10] Ductwork within a ceiling or floor system should either be enclosed with fire-resistant material, or equipped with a damper system to prevent fire from entering the duct and spreading to other portions of the building.

Gypsum wallboard is one of the most common building materials in modern construction. It is used to cover walls prior to plastering, painting, or other wall finishes. It is similarly used on ceilings. Gypsum, or dihydrous calcium sulphate,[11] has a high level of fire resistance, and therefore is used in the construction of fire barriers or other building protection systems. An example of this is the construction of gypsum-covered partitions in attics to prevent the horizontal spread of flames and smoke during a fire.

During a fire, chemically combined water within gypsum is slowly released as steam. This process is called calcination.[12] The water that is released helps to retard the heat flow caused by the fire. A special type of gypsum core, classified as type X, contains expanded vermiculite and siliceous clays, which hold in water and allow more water to be released during calcination. The diagram on the following page shows a temperature gradient for a thickness of type X gypsum based on two-hour exposure to the ASTM standard time-temperature curve. Calcination occurs to a depth of about two inches. This calcination area is generally reinforced with glass fibers to help prevent the gypsum from crumbling, thus decreasing the fire resistance.

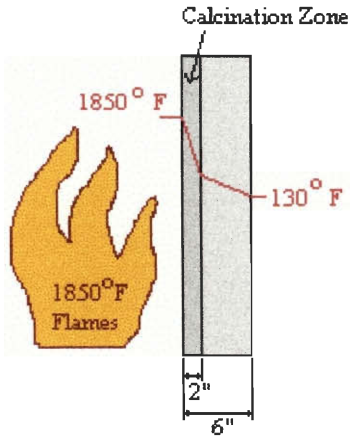


Figure 2.1.6. Temperature gradient of gypsum in a fire.

Materials are tested based on standards described by ASTM E 119. This provides a time-temperature curve intended to represent fire development in an average room with moderate ventilation and well-insulated enclosing surfaces.[13] Large furnaces, which can simulate fire conditions, are constructed, and materials are placed in them in a manner similar to the manner they would be installed in an actual building. Similarly, applied loads are also simulated. This procedure gives a good indication of the performance of a single building element in fire conditions. However, it does not show how an entire building structural system would behave during a fire. Thus, care must be taken in using test results for the design of buildings. One must recognize that these tests can only show how a single element will react to fire conditions, and that this reaction will affect other elements of the building.

## 2.2. Interior Furnishings

There are extensive fire codes regulating structural elements of buildings. However, there are few, if any, codes which elate specifically to the contents of a building. The furnishings within a building generally influence the ignition of a fire to a much greater extent than the structure. It is very possible for a building whose structure has a low fire rating to survive the ignition of a fire due to the fact that the interior contents did not allow the fire to spread enough to involve the structure. On the other hand, a structure with an impressively high fire rating might burn to the ground if its contents allow flashover (or full room involvement, the condition where all combustibles in the room are surface burning[14]) to occur so quickly that the fire department cannot reach the building in time to battle the fire. Once flashover has occurred in a room, the fire department can generally only try to stop the fire from spreading to other rooms, and must wait for all fuel packages within the room to be used up by the fire.

A given building can contain hundreds of different pieces of furniture or other contents, made of many different materials. Some of these do not burn, but most will. Some burn quickly, while other may just smolder for a long time before actually igniting. It is important to have a perception of how different materials will behave in a fire situation in order to have an accurate view of the hazard present in a space. All of the furniture fire characteristics in the following paragraphs are based on tests performed by the U.S. Department of Commerce, Center for Fire Research, using a furniture calorimeter, a device used to measure mass loss and heat release rates of furniture in fire situations.[15]

Almost every type of space has, at some point, chairs in it. These range from "easy chairs" designed for comfort, to office chairs. Chairs are available in a wide range of materials, from wood to plastic to metal. Some are padded, and some are not. Five chairs were tested in this test. The first, an easy chair with a wood frame and California foam padding (so named because it meets the requirements of California State Bulletin 117[16]) showed by far the highest heat release rate of all chairs tested, greatest total heat release, and greatest peak mass loss. This chair would release more than enough heat to cause flashover in an average room, and to spontaneously ignite nearby objects.

The next chair tested was a one-piece molded polystyrene foam frame with polyurethane foam padding. It had a peak heat release rate of less than half that of California foam chair, but it would still be enough to cause flashover to occur in an average room.

The chair that performed best in the test was constructed of an exposed wooden frame with a seat cushion of solid polyurethane foam. It had a comparatively small heat release rate and produced the least smoke of all chairs tested. This chair would most likely not cause flashover in an average room. The other chairs tested here did not show any significant results, but fell in the range between the second chair discussed above and the last. Only the first two chairs mentioned here would most definitely cause flashover in an average room.

These results clearly show that the average person might not be able to perceive the level of hazard imposed by a certain piece of furniture. Two different chairs in the same room might look similar, but one might be padded with California foam, while the other might be cotton or polyurethane. An ignition in the first chair would quickly lead to untenable conditions in the room, while one in the second might simple smolder for a while before bursting into flames. It is very hard for the average consumer to judge which type of chair material is safest. The wood frame chair performed by far the best in these tests, even though many people perceive wood as being highly combustible.

Also tested were waiting room and patient chairs, which aren't generally found in residences. These chairs, with construction ranging from metal to molded fiberglass to plastic, generally exhibited heat release rates lower than the ones observed in the tests of easy chairs discussed above. Of the eight chairs tested, the only one that would seem to be able to cause flashover in an average room was constructed of molded plastic. The high heat release rate did not occur at the first peak, however, but instead after the chair had melted and formed a pool of rapidly burning plastic. This is interesting because many people do not realize how violently plastic can burn, and how it can turn into molten liquid while it burns, thus spreading fire to its surroundings. Luckily, molded plastic chairs are not generally found in residential settings.

Possibly the most interesting and influential tests involved sofas and bedding. These tests were important because fires ignited on these types of materials are among the most common reported residential fires. Three different sofas were tested – one with a wood frame and California foam padding, another with a metal frame and solid polyurethane foam padding, and the last with a wood frame and solid polyurethane padding.

Similar to the easy chair with California foam padding, the sofa with this material burned rapidly and released a very high amount of heat. It would easily cause flashover in an average room, and would also easily ignite any other combustible object in the same room. It should also be noted that this sofa also released the largest amount of carbon monoxide of all furniture in this test. Such a sofa is very common in residential and institutional spaces, but the risk is rarely recognized. An article of smoking material, if dropped onto this sofa, could easily ignite it and lead to full room involvement of the space. Both polyurethane foam-padded sofas performed relatively well in the test, with the metal-framed sofa performing the best overall. This sofa would most likely not lead to flashover. The wood framed version might lead to flashover if the ignition was left unnoticed for a sufficient amount of time.

Two different mattresses were also tested. The first was 40% cotton felt, 40% polyurethane foam, and 20% sisal, with a wood frame and a plastic net coil spring unit. It was intended that this mattress would be ignited using a cigarette as a heat source, but the testers were unable to ignite the mattress using this method, so a burner was used instead. This mattress and boxspring combination performed rather well, with a different heat release peak for each of the two components. Most likely, this mattress would not result in full room involvement on its own.

The second mattress tested was a full-size spring-core mattress with a quilted ticking over layers of polyurethane foam and fiber batting. Ignition of the sheets on this mattress resulted in a fully involved mattress within a few minutes. The peak heat release of this mattress would be enough to cause flashover, and clearly anyone sleeping on this mattress when it ignited would not have much time to be alerted to the fire and get out of the room safely.

The last test looked at wardrobe closets and a bookcase. Two similar metal wardrobes were tested, one with a pile of rags as a fire load, and the other with a box containing some paper in this role. The closet containing the rags reached a high peak heat release rate very quickly, but this was only due to the burning of the rags. The same closet with only paper inside did not result in a high peak heat release rate. Thus, it is clear that in the case of metal wardrobes, the contents govern the level of fire hazard and growth potential. These were the only wardrobes that were not viewed as being able to easily cause flashover.

Next, unfinished Douglas-fir plywood closets were tested. These produced very high heat release rates regardless of their contents, and would easily result in rapid full room involvement. Commercially finished wardrobes also performed poorly, and even fire retardant paint did not seem to have much of an effect on their performance, even though it did reduce the peak heat release rate somewhat.

A particleboard wardrobe was also tested. It was filled with fabrics and had an attached desk on one side. Two different peak heat release levels were observed, due to the initial burning of the closet and its contents, and then the burning of the desk. While the peak heat release rates were not quite as high as those experienced during the tests of some of the plywood closets, the total heat release was the greatest of all tests performed. This is due mainly to the fact that this piece of furniture had the largest mass of all piece tested. This wardrobe would most like result in eventual flashover of an average sized room.

The last piece of furniture tested here was a plywood bookcase, and it showed by far the lowest heat release rate of all test pieces. The fire in the bookcase self terminated in less than a minute after the ignition flame was removed. The majority of data collected in the tests involving the other pieces of furniture were not recorded for this bookcase because the values were too small.

All of this test data leads to a simple conclusion: furniture burn characteristics are not universal, and the true hazard of a room depends largely on the materials included in its furnishings. It is very difficult to distinguish between different types of materials, however. While it is true that most people will recognize that a metal bookcase would most likely burn slower than a wood bookcase, very few people would know the difference between a sofa stuffed with California foam padding and one with any other type of padding. This difference is very important when it comes to fire growth potential, but it is a difference that is not visually recognizable to most people, nor is it common knowledge to the average consumer.

## 2.3. Room Layout

One element of interior furnishings that the average consumer can judge in terms of hazard is room layout. While one might not be able to accurately label various materials as fire hazards, one can usually judge whether or not a certain room layout would lead to a highly hazardous condition is a fire was to start. Generally, a person's level of comfort within a room is governed by the orientation of different pieces of furniture in the room, as well as the size of the open spaces between the furniture. Refer to the picture below.

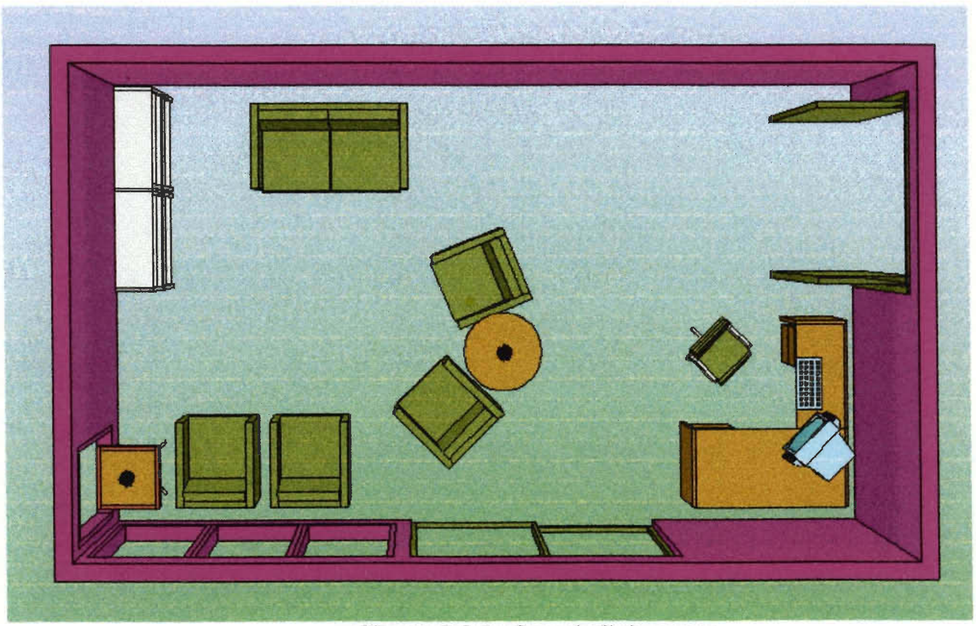


Figure 2.3.1. Sample living room.

The room above can be considered to be an average living room like that found in many modern homes. Its dimensions are approximately 20' by 30'. In its present configuration, most people would view it as being comfortable, without many hazards. There is a good deal of space in which one can move about, and while some pieces of furniture are situated close to each other, essentially creating large fuel packages, they are spaced out enough, and the room is large enough, to keep one from feeling confined or crowded. Let's now imagine the same furniture layout in a room that is only 10' by 20'.

There would be much less free space in which someone could walk, and all of the furniture would be very close together, allowing a small fire started, for example, in the sofa to spread to other objects quickly. If all of the padded furniture within this room contained California foam, flashover could be reached within a matter of minutes after ignition. Also, imagine that a person is sleeping in the chair located in the lower left corner of the picture, and a fire starts on the sofa. If the person is woken up by a smoke detector, there might not be enough room for him to move out of the room to safety.

Next, imagine that the room is not kept as neat as it appears in the picture. If there were papers and articles of clothing strewn about, a wastepaper basket overflowing next to the desk, and other general clutter in the room, one might feel much less comfortable within the space. This clutter could act as kindling to help ignite larger fuel packages. In the clean room, a carelessly discarded match or cigarette might just burn itself out, but in the cluttered room, it might ignite a piece of paper or fabric and lead to a much larger, life-threatening fire.

Next, observe the office shown below.

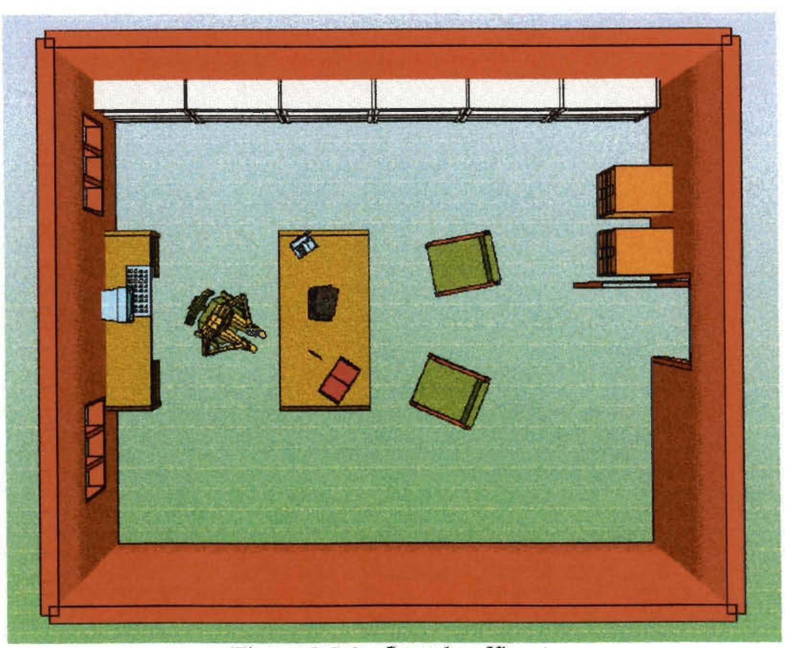


Figure 2.3.2. Sample office 1.

This office is rather large for a single office at approximately 15’ by 15’. It is also uncluttered and there is a good deal of open space. Most people would feel very comfortable in this office, because there are few large, easily combustible fuel packages, and escape from the room would most likely be unhindered. Compare this office to the one shown below.

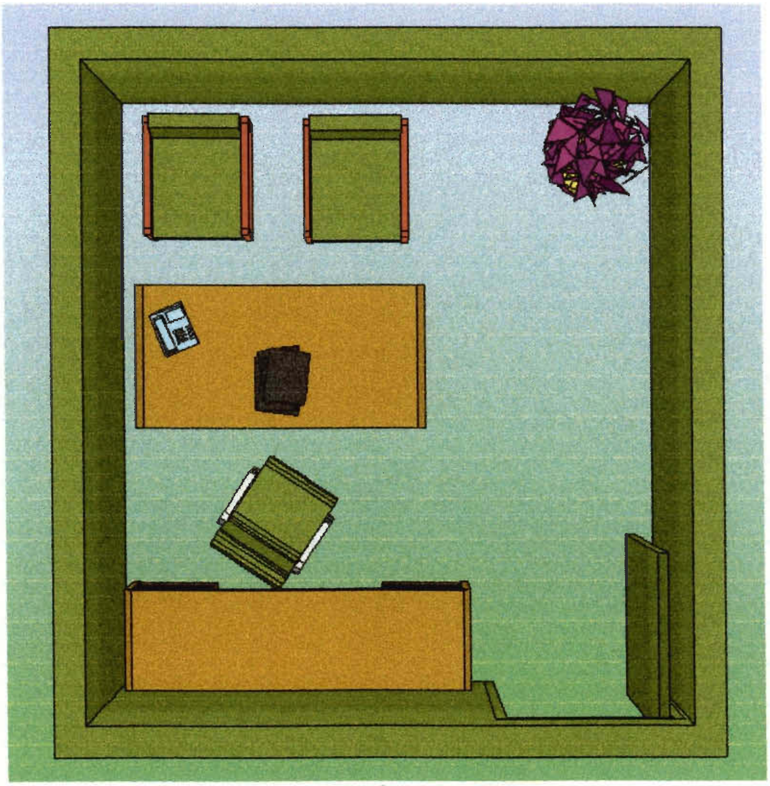


Figure 2.3.3. Sample office 2.

This is also a one-person office, but it measures only 8’ by 10’. The same basic types of furniture are used in this office, with omission of the wall-length bookcase, which would obviously not fit. It is clear that there is little space in which to maneuver, and most people would feel cramped and uncomfortable spending time here. Imagine a fire starting in a wastepaper basket placed beside the desk. If there was sufficient fuel in the basket to allow for a moderately large initial fire, then the desk could catch fire, followed by the other pieces of furniture, which are located very close to the desk.

Theoretically, everything in this office could be considered a single fuel package, because it is all so close together. A small ignition could rapidly lead to full room involvement, if it remained undiscovered for long enough to grow to just a few feet high. While this office layout would generally be considered uncomfortable or hazardous, it is not at all uncommon. It should be noted that office space is generally sprinkled, which would lessen the possibility of full room involvement if properly installed. Regardless, the layout of this room plays a huge role in an occupant's feeling of comfort, or lack thereof.

Notes

[1]*Fire Protection through Modern Building Codes*. (New York: American Iron and Steel Institute, 1971.) 153.

[2]Stanzak, W.W. and T. T. Lie. "Fire Resistance of Unprotected Steel Columns." *Journal of the Structural Division.* ASCE, Vol. 99, No. ST5, May 1973.

[3]Egan, M. David. *Building Firesafety.* (New York: John Wiley & Sons, 1978.) 70.

[4]Egan. *Building Firesafety.* 70.

[5]Egan. *Building Firesafety.* 70.

[6]Marchant, E. W. *Fire and Buildings.* (New York: Barnes and Noble, 1973.)

[7]Egan. *Building Firesafety.* 108.

[8]Egan. *Building Firesafety.* 90.

[9]Egan. *Building Firesafety.* 91.

[10]Egan. *Building Firesafety.* 95.

[11]Egan. *Building Firesafety.* 76.

[12]Egan. *Building Firesafety.* 76.

[13]Egan. *Building Firesafety.* 80.

[14]Fitzgerald, Robert W. *The Anatomy of Building Firesafety*. (Worcester, MA: Worcester Polytechnic Institute, 1998.) Chap. 3, 11.

[15]Lawson, J. Randall, W. Douglas Walton, and William H. Twilley. *Fire Performance of Furnishings as Measured in the NBS Furniture Calorimeter.* (Washington, D.C.: U.S. Department of Commerce, Center for Fire Research, 1984.) 3.

[16]Lawson, Walton, and Twilley. *Fire Performance of Furnishing.* 16.

## 3. Basic Fire Theory

In order to have a better understanding of the focus on fire detection devices, the resulting fire suppression, and building construction, some general information about fire is presented first. Flame can spread in either a vertical direction or a horizontal direction. Flame spreads more rapidly in the vertical direction because currents of heated air rush upward ahead of the flames and preheat the fuel that will be consumed next. When flames travel in the horizontal direction, the spread is much slower because the heated currents of air move away from the next fuel supply.

Due to the nature of heated currents of air to travel upwards, the surface temperature of ceilings is much greater than the temperature of floors. This means that materials used to cover floors are potentially less hazardous than those used for ceilings. However, floor coverings such as carpets can be a major source of fire spread throughout a building. Carpets undergo a test in order to evaluate the potential of fire propagation along the surface of that carpet. A small section of the carpet is installed in its normal position and exposed to a varying radiant heat source. The rating is determined by how far the flame spread until the piece extinguishes itself. The higher the heat source needs to be in order to propagate the fire represents how much resistance the carpet will pose to a fire.

The concept of a fire load was introduced in order to facilitate the measurement of the endurance of an office space or similar rooms to a fire. A fire load is the weight of combustible materials per square foot of floor area. The weight of the fuel load is equivalent to the weight of the wood needed to contribute the amount of heat energy that results from the fuel contributions of the combustibles in the room. The table below shows some common fire loads in pounds per square foot.[i]

| Type of Space | Fire Load (psf) |
|---|---|
| **Apartments** | 8-10 |
| **Classrooms** | 7 |
| **Library stacks** | 36 |
| **Offices** | 2-45 |
| **Reception areas** | 3-9 |
| **Restrooms** | 2-10 |

Table 3.1. Fire loads for various occupancies.

Heat release of an object is determined by the fire load, surface texture and area. An example would be that a stack of papers would give off the same amount of heat as an equivalent weight of shredded paper. The difference is that the shredded paper would have a much greater rate of heat release.

Notes

[1]Egan, M. David. *Building Firesafety.* (New York: John Wiley & Sons, 1978.) 25.

## 4. Methods of Fire Control

There are four different methods of fire control used in buildings today. They are control by construction, control combustion process, automatic suppression, and manual suppression[1]. When all these methods have been practiced and their individual components are in working order than the potential of a fire is greatly lessened.

### 4.1 Control by Construction

Control by construction takes place mainly when the building is raised. The main focuses of control by construction is to protect the structural components, keep the fire resistance of walls, floors, and passages at a maximum, and to have panel vents and shafts in order to control smoke and remove heat. Structural components are protected by surrounding them with either fire retardant enclosures or by a sprayed-on fire retardant substance.

In order to ensure that floors, ceilings, and walls have the maximum fire resistance, possible breaches in their respective barriers must be avoided. A hole in a wall for example allows flame to spread thereby circumventing the barrier that should be present in a wall within a building. A poke-through assembly is a device such as a telephone port or computer jack that is drilled through a floor to allow for electrical fittings. In order to prevent the spread of flame these fixtures are usually sprayed with an insulation undercoating, have a intumescent mastic coating on the conduit, or they have heat shields. If a poke-through device was left unprotected it would lower the fire resistance of the floor to only a few minutes. In addition, ceilings which have a large percentage of area taken up by air ducts need to have effective fire control devices. A mechanical system called a damper is used to prevent the ductwork from spreading the fire. A damper is controlled by a heat sensitive instrument such as a heat-sensitive fuse or remotely by a fire detection instrument. When the instrument detects a fire a blade closes over the opening inside the duct, cutting off the passage to fire.

Doors play a very important role in the prevention of the spread of flames. A closed door in a corridor presents a significant deterrent to the horizontal spread of flame. Because of their importance doors are given a thorough fire test. A fire door is placed in its frame and installed in a wall construction. The door and its frame are then subjected to a fire exposure according to the accepted ASTM standard time-temperature curve. The door passes the test if it stays securely within its hinges and can withstand the impact from a stream of water from a standard hose on its heated side. Doors that are placed within fire walls or partitions must have a fire resistance close to that of the surrounding wall. If the door does not, than a sprinkler can be positioned near the door to aid in blocking the movement of flame. Because the door needs to be in the closed position in the event of a fire, many doors are held open with magnetic holders. These holders allow for easy passage through the door but if a fire is detected the magnets will release the doors and the doors will be firmly shut. This type of mechanism prevents fire doors from being blocked open with wedges or other objects that would hinder its performance in the event of a fire. Also fire doors need to be constructed so that they open in the direction of traffic when people are exiting the building, and they need to be self closing with a retarder that slows down the closing of the door to a safe speed.

The placement of stairs needs to be carefully though out. Stairs provide an easy passage for flame to spread to different levels of a building. Usually the materials used in stairwells have a high fire resistance for this reason and fire doors are located at the entrances and exits to stairs. An example of bad placement would be a large house with open stairs that ran up the center of it connecting the different floors. Lack of fire doors would change this stairwell into a chimney in the event of a fire. The flames would spread without any barriers to the different floors and quickly consume the whole building.

## 4.2 Controlled Combustion Process

The second method of fire control is controlled combustion process. The first concern of this process is the combustibles located within a room. The quantity, properties, and distribution of the combustibles determine the extent of fire hazard. An example would be a common office. If the office had some books on a shelf and the desk was clean the potential for flame spread would be less then if a whole wall was lined with books and the desk was littered with papers. A lot of material stored in wooden cabinets presents more of a hazard than metal filing drawers. In addition the finishes that are applied to the furniture and walls will change how readily combustible they would be in the event of a fire. What the furniture could also allow for the release of toxic fumes when burned.

The measurements of the room make a difference in the evaluation of a hazard. The volume, shape, and ceiling height contribute a great deal to the potential of hazard calculations. Flashover is when flames sweep across the room and involve most combustibles in fire. Flashover occurs when room temperatures near the ceiling increase rapidly to 800° to 1200°F. Therefore if the height of the ceiling is really large than the potential for flashover is lessened and the hazard for people in the room is also lessened. The volume of a room can affect how closely fuel packets are near each other. A small room with an average amount of clutter presents a good potential for flame spread, but a larger room with the same amount of clutter presents a lower level of potential. Lastly the thermal properties of the walls, ceilings, and floors would affect the thermal build-up in the rooms.

## 4.3 Automatic Suppression

The third method of fire control is automatic fire detection and suppression. Early detection and warning is imperative in the attempt to prevent loss of life or harm to the occupants of the building. The alarms to the occupants need to be substantial in order that they are able to achieve their task. The most common device for warning is a horn strobe station. These can be activated by an electronic signal sent from an early detection system of they can be activated by a nearby person, simply by pulling on its lever. The horn needs to be loud enough to be heard over the commotion of an emergency; therefore, the minimum volume is 85 decibels at a distance of ten feet from the horn. The strobe is attached to the horn and positioned in such a manner so that it can be seen. The strobe is supposed to alert people who are hearing-impaired to the emergency taking place around them. The minimum height for a horn strobe is 80 inches off the floor, this height does not account for obstructions such as store displays. Besides allowing for an increased margin of safety for the occupants of a building, early detection allows the fire department to be rapidly informed of the fire or that automatic suppression of the fire can be initiated.

There are different kinds of detectors, which have different characteristics that make them more suitable for a particular fire hazard. For example photoelectric smoke detectors work well for detecting smoldering fires, an ionization smoke detector for flaming fires, and an infrared detector for flash fires. A smoke detector works because the smoke will interrupt a very small electric current that is passing between electrodes in an ionized environment. When the current is interrupted the alarm sounds. The last type of detector is a heat detector. There are two different types of heat detectors. The first is one in which there is a preset temperature usually 135°F, and when the detector reads that temperature it is set off. The second type of heat detector is one that measures the rate the temperature rises. When this measurement corresponds to a certain preset rate usually 15°F per minute, the detector activates. A heat detector is best suited for conditions with uncontrolled rapid heat increases that will most probably escalate into a full fire. A heat detector works by incorporating a physical change in materials to connect an electric circuit. At the surface of the heat detector that is within the room is a metal plate. The plate is constructed by joining two different metals, and when heated they will bend. This works because when the heat in the room gets to a certain temperature the metal bends enough to make contact with a terminal. By making contact an electrical circuit is completed and the alarm is sounded.

The placement of smoke detectors is very important. The detector needs to be placed in a location where the air currents will actually bring the smoke to the detector and not by it. General guidelines to follow would be to place the detector in the center of the room away from any obstructions such as beams or over hangs. For this reason smoke detectors are placed at the ends of stairways because smoke will collect at the ends of stairway. Also detectors need to be placed in the sleeping areas of a residence because they need to alert the occupants of an emergency in the night.

According to the National Fire Protection Service records, automatic sprinklers are 96% effective in suppressing fires.[2] The reason why they are not more effective is because the water control valve is prematurely closed or it was closed for some reason before the fire. The water that is showered from a sprinkler serves many uses in fire suppression. The water dampens materials that have not yet been consumed, preventing them further from spreading flame. It removes the sources of oxygen for the fire by making steam in the room. In addition, the water cools materials that are burning by coming in contact with the materials. A sprinkler is designed to shower the area beneath and around it with a controlled division of water particles. In order for a sprinkler to be effective its water discharge must not be obstructed. Problems can arise in buildings where renovations are done because new ductwork or conduit will be placed under the sprinkler heads, thereby weakening their effect on a fire. Sprinklers usually turn on when a certain temperature is reached, these temperatures can vary depending on the environment of the sprinkler. Most work by having two levers attempting to move in opposite directions. At a predetermined temperature the brace that held the levers back will break, thereby allowing the two levers to travel out from the center of the sprinkler. This activates the water.

Another type of automated suppression system is one that uses carbon dioxide. Carbon dioxide is used because it is nontoxic, does not leave a residue after discharge, and it does not damage electrical equipment like water. Since it is nontoxic and does not leave a residue a common application for a carbon dioxide system is over a cooking area such as a grill. A detector and a nozzle are positioned over the grill, when the detector is tripped the nozzle will automatically discharge the carbon dioxide directly onto the surface. The carbon dioxide is stored as a liquid, but when it is released under pressure it turns into a gaseous state. The intention is to smother the fire out.

A halon system discharges halogenated hydrogen into the air. It too has a detector and a nozzle, however it is usually discharged in an attempt to create an environment uniformly distributed halon. Any automated air flow devices must be shut off when the nozzle is activated and any doors to the area should close in order to help the distribution of the halon. Since halon is five times heavier than air it will smother a fire. Museums and libraries commonly use this type of system.

## 4.4 Manual Suppression

The last method of fire control is manual suppression. This method incorporates a human into the process of putting out a fire. A fire extinguisher is a handheld device, which is meant to handle very small isolated fires. Its position should be clearly marked and should be positioned so that if one is needed it will not be carried more than 75 feet. A fire extinguisher needs to be inspected yearly to insure it will operate correctly when needed. There are different types of extinguishers. The typical type in the past was a carbon dioxide extinguisher, which operates in the same manner as the automated carbon dioxide system mention previously except it is manually operated. The problem was these extinguishers were restricted in their use too much. Another type is the A type extinguisher which can be used on any type of fire that would leave an ash. An A type extinguisher uses pressurized water to put out a fire. One problem with this is the force of the water can knock over the source of the fire causing a larger problem. The trend today is to go towards multipurpose extinguishers. These have the added benefit of not usually being the wrong kind. It was a common occurrence for a person to attempt to put out a fire with the wrong type of extinguisher because they did not know there was a difference. A multipurpose extinguisher would alleviate some of those mistakes.

Another type of manual suppression system is a standpipe. A standpipe system has water hoses on every floor of a building or a place for a fireman's hose to be attached. Standpipes are usually positioned in stairways because this means that the exits will be open while a fireman is fighting the fire. There are two types of standpipes. The first is called a dry system because in order for the system to work the outside end must be connected to a fire hydrant or other water supply. The second type is a wet standpipe. These incorporate a storage tank of water that is emptied using the force of gravity. The storage tank is connected to a nearby water main for refilling purposes. Because the tank is emptied using gravitational forces the water in the pipes is always under pressure.

Notes

[1]Egan, M. David. *Building Firesafety.* (New York: John Wiley & Sons, 1978.) 36.

[2]Egan. *Building Firesafety.* 128.

## 5. Hazard Analysis Survey

Appendix A of this report contains a survey that is intended to be used to observe people's ability to recognize hazards and to rate a hazard's level of severity. The intentions and results of this survey are discussed below.

### 5.1. Construction and Intentions of the Survey

The main goal of this survey is to simulate situations in which an average person might find himself, and to ask the person how he would react to the circumstances. The survey is rather extensive, and in the form of a focus group, where all participants are asked the same questions and have several alternatives for responses. Many of the questions ask the person to rate their view of some aspect of a situation, such as personal comfort, hazard, or safety. These types of questions are designed to determine what factors people believe are most important in defining the presence of, or the lack of, hazard within a space. With enough participants, definite trends should appear within the survey results. For example, it might be found that most people do not believe the specific location of a smoke detector is important, as long as it is functional. This is just a hypothetical, as-of-yet unconfirmed example result, but such information might become apparent when the survey results are analyzed.

Another type of question included in this survey places the survey participant in a specific situation, and gives him several alternatives with which he could deal with the circumstances. This type of question is intended to help define behavioral tendencies in people who are placed in potentially hazardous situations. Many theories discussed in Section 1. (Human Behavior, page 6) will be analyzed based on the behavior predicted by these questions.

## 5.2. Interpretation of the Survey Results

Due to time constraints, the survey has as of yet not been presented to its intended audience of laypeople, fire protection engineering students, practicing engineers, and firemen. As a form of closure, the results of the survey will be predicted here, and the actual survey will be included for possible completion at a future time.

Because the survey has not been completed, we do not have any data from which to base conclusions regarding how people would act in specific situations, or how they would view different hazards. We must therefore make only relatively vague predictions. We believe that in everyday life most people do not actively look to identify hazards around them. When they are presented with specific examples of situations that might be hazardous, such as those presented in the survey, most people could probably identify the hazard and correctly rate its severity. This leads us to believe that if an actual hazardous situation was to occur, most people would be able to recognize it, but they might not react to it appropriately. All of the pictures included in the survey were taken within occupied buildings. The occupants did not seem to recognize many of the hazards that were present or to concern themselves with correcting these hazards.

We believe that cost is a large factor governing the presence of hazards. One could walk through an average building and point out hundreds of hazards, but fixing each of these would not be cost effective. It would be much more efficient to simply make the occupants of the building aware of any major hazards, and to teach them how to deal with most hazardous situations that might occur. Fire drills, planned and posted escape procedures, and other organizational methods are among the best ways to promote life safety.

## Appendix A. Survey

*Hazard Analysis Survey*

The following is a presentation of common situations occurring within the spaces that average people occupy. Please answer the questions based on your initial reactions to the situations. We request that you do not analyze any single situation beyond your initial reactions.

*Part 1:*

Automatic Fire Suppression Within a Building

*The fully operational sprinkler system shown below is intended to protect an exit hallway. Rate your view of the effectiveness of this sprinkler in protecting the hallway.*

- Highly effective
- Somewhat effective
- Somewhat ineffective
- Very ineffective

*This sprinkler protects your main exit hallway. Rate your view of the effectiveness of this sprinkler in protecting the hallway*

- Highly effective
- Somewhat effective
- Somewhat ineffective
- Very ineffective

*Workers are in the process of installing this sprinkler system. Rate your view of the adequacy of the support shown.*

- Highly adequate
- Somewhat adequate
- Somewhat inadequate
- Highly inadequate

*This is a main supply line for a sprinkler system. Rate your view of the adequacy of the support shown.*

- Highly adequate
- Somewhat adequate
- Somewhat inadequate
- Highly inadequate

*Part 2:*

Barriers Within Buildings

---

*This door will close automatically in the event of a fire. There is an exit at the far end of the hall. Rate your view of the level of benefit the door provides for the occupants in the case of a fire*

- ☐ Very beneficial
- ☐ Somewhat beneficial
- ☐ Somewhat non-beneficial
- ☐ Very non-beneficial

---

*Two offices of the same company are connected by the door shown below. You are the nearest person to this door when the fire alarm sounds. What actions would you take?*

- ☐ I would pass through, closing this door behind me, and exit through the door I can see at the end of the hall.
- ☐ I would pass through, leaving the door open so that others may see and use the exit at the end of the hall that I used.

---

*The doors below were propped open for ease of passage by occupants of a hospital to the exit seen beyond. Rate your view of the level of safety afforded to the occupants by this practice.*

- ☐ Very safe
- ☐ Somewhat safe
- ☐ Somewhat unsafe
- ☐ Very unsafe

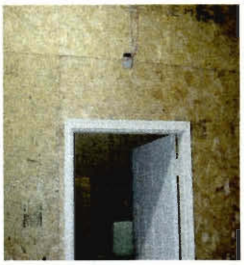
---

*This opening is located in a utility room away from commonly occupied spaces. Rate your view of the hazard that is imposed by this opening in the case of a fire in this room.*

- ☐ Highly hazardous
- ☐ Somewhat hazardous
- ☐ Somewhat safe
- ☐ Very safe

---

*This hole has been cut in this wall to allow for the passage of wires. Rate your view of the hazard imposed by this hole in the event of a fire in this room.*



- ☐ Highly hazardous
- ☐ Somewhat hazardous
- ☐ Somewhat safe
- ☐ Very safe

*This former chimney was converted into a passage for utilities. It is made of brick and mortar throughout. Rate your view of the hazard imposed by this usage of the passage.*

- Highly hazardous
- Somewhat hazardous
- Somewhat safe
- Very safe

*Rate your view of the hazard imposed by this opening if a fire were to start in this room.*

- Highly hazardous
- Somewhat hazardous
- Somewhat safe
- Very safe

*The janitor in your building has propped this door open. Rate your level of comfort in this situation.*

- Very comfortable
- Somewhat comfortable
- Somewhat uncomfortable
- Very uncomfortable

## *Part 3:*

## Occupant Egress

*Fire alarms are sounding in the building containing the hallway below. You step out of an office and see the view pictured here. What is your reaction?*

- Proceed down the hallway in this direction, assuming there must be an exit.
- Wait for other people to come and follow them.
- Return to your office and wait for the Fire Department to arrive and evacuate you.

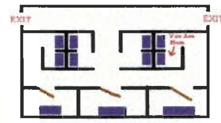
*This is the secondary fire exit in an office building. Choose the level of hazard you think this exit would present in an evacuation situation.*

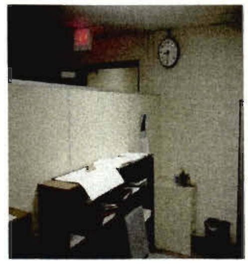
- Very high hazard
- High hazard
- Low hazard
- Very low hazard

*What level of hazard do you feel the partition shown below poses to the occupants of the office?*

- Very high hazard
- High hazard
- Low hazard
- Very low hazard

*Rate your level of comfort within the space shown here.*





- Very comfortable
- Comfortable
- Uncomfortable
- Very uncomfortable

*Do you feel that this exit is properly marked? Rate the positioning of the sign.*

- Very well positioned
- Well positioned
- Poorly positioned
- Very poorly positioned

*This occupied building is under renovation. The door has been barred for security purposes. Select the option from the list below that best describes the situation.*

- Very good practice
- Good practice
- Poor practice
- Very poor practice

*Would the lightweight material blocking this exit be enough to pose a hazard to the occupants of this building?*

- Yes, this poses a serious hazard.
- Yes, this poses a moderate hazard.
- Yes, this poses a low hazard.
- No, this poses no hazard.

## *Part 4:*

## Detection, Notification, and Suppression Systems

*This functional smoke detector is positioned directly outside a bedroom. Rate the position of the detector.*

- ☐ Very well positioned
- ☐ Well positioned
- ☐ Poorly positioned
- ☐ Very poorly positioned

*This functional smoke detector is positioned above the landing at the bottom of the stairs leading to a basement. Rate the positioning of the detector.*

- ☐ Very well positioned
- ☐ Well positioned
- ☐ Poorly positioned
- ☐ Very poorly positioned

*This functional smoke detector is positioned in a vestibule that connects two bedrooms and a bathroom with the central hall of the house. Rate the positioning of the detector.*

- ☐ Very well positioned
- ☐ Well positioned
- ☐ Poorly positioned
- ☐ Very poorly positioned

*How hazardous do you feel this primary exit would be to the occupants of the building in the case of a fire?*

- ☐ Very hazardous
- ☐ Moderately hazardous
- ☐ Slightly hazardous
- ☐ No hazard

*This sign marks the lone fire extinguisher in this office space. It is high enough so everyone in the office can locate it. Rate the positioning of the sign.*

- ☐ Very well positioned
- ☐ Well positioned
- ☐ Poorly positioned
- ☐ Very poorly positioned

*This alarm/strobe is located in a storage room. What level of hazard is created by objects stacked on this shelf?*

- ☐ High hazard
- ☐ Moderate hazard
- ☐ Low hazard
- ☐ No hazard

*This space is the future location of a department store. Alarm/strobes like the one shown are placed uniformly throughout the space. How well would these alarm/strobes serve their purpose in a retail setting?*

- Very well
- Well
- Poorly
- Very poorly

*How important is it to label the position of every fire extinguisher within a building?*

- Extremely important
- Important
- Unimportant
- Extremely unimportant

*You are in your office when a small paper fire starts in your trash can. You step out into the hallway shown below. Which action do you take?*

- Go retrieve the fire extinguisher that you know is just beyond the glass doors, and attempt to extinguish the fire yourself.
- Proceed to the nearest exit, and pull a fire alarm as you leave the building.

*The nearest fire exit is located at the end of the hall pictured below. Besides the fact that it hides a fire extinguisher when it's open, is there anything wrong with this automatically-closing fire door?*

- No, there is no problem with the fire door pictured here.
- Yes, there is something wrong with the fire door pictured here.

*This fire extinguisher has been inspected recently and is located in an office. The office workers have been informed of its location. If you were a worker in this office, would you trust it to put out a small office fire?*

- Yes, I would use it in the case of a small office fire.
- No, I would not use it in the case of a small office fire.

*Partitions of the height shown below were used to lay out this office. Rate your feeling of comfort in regards to safety within this office.*

- Very comfortable
- Somewhat comfortable
- Somewhat uncomfortable
- Very uncomfortable

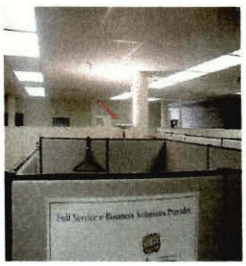
*This main sprinkler system shutoff was just recently inspected, and has been put back into service. Rate your level of trust that it will function properly in the case of a fire.*

- Very trustful
- Somewhat trustful
- Somewhat distrustful
- Very distrustful

*Part 5:*

Sources of Fire Growth

*You are the owner of this company. You notice one of your employees has brought in and set up the light seen below. What should you do?*



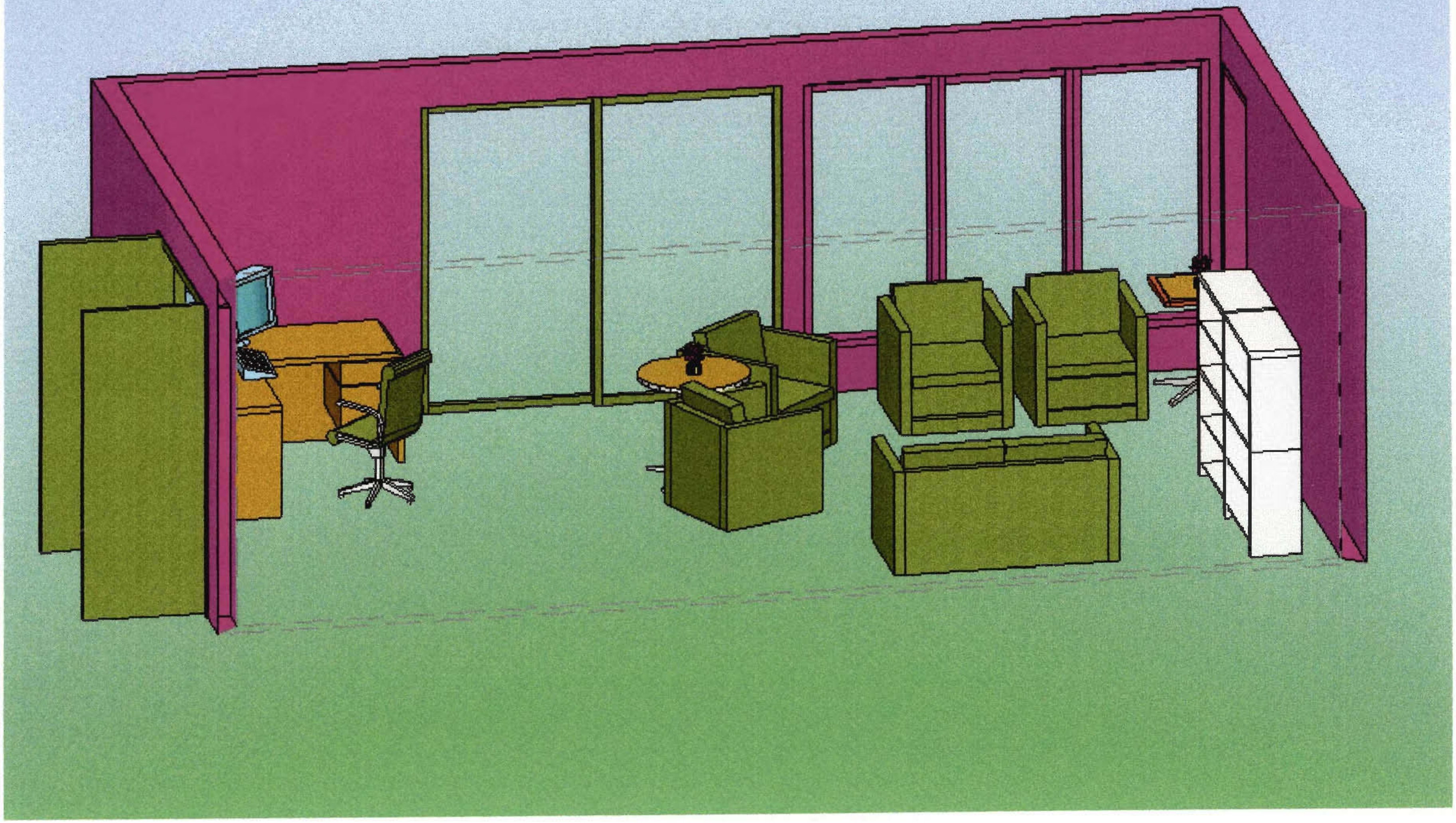
- Allow the employee to keep the lamp where it is.
- Ask the employee to move the lamp away from the partition.
- Ask the employee to remove the lamp from the office.

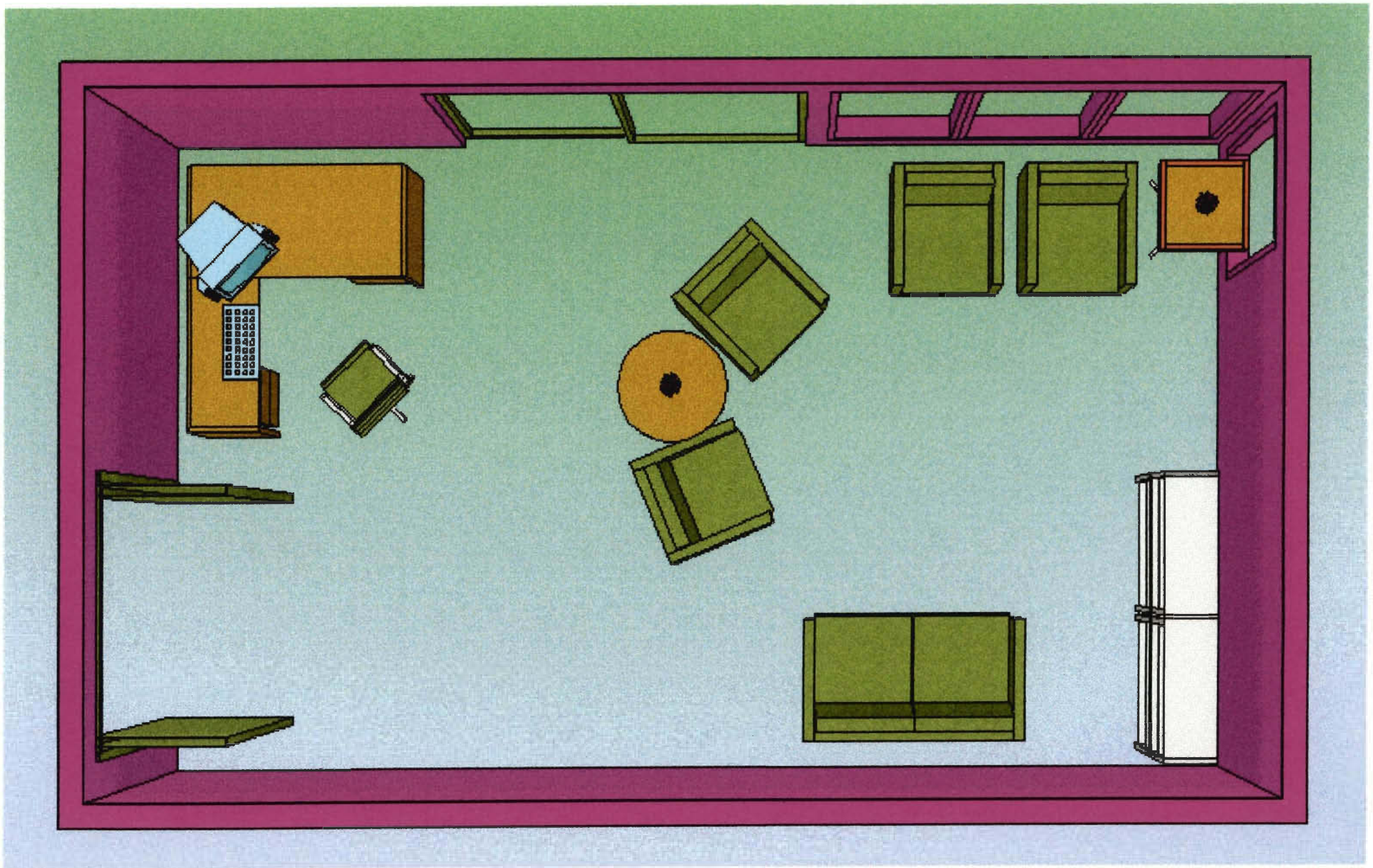
*This former office space is now being used as storage space. It is equipped with a sprinkler system, and also contains smoke and heat detectors. An alarm would sound in the fire station if smoke or heat was detected. Rate your view of the safety of the workers in the office next to this room, which has it's own exits.*

- Very safe
- Somewhat safe
- Somewhat unsafe
- Very unsafe

## Appendix B. Sample Room Data

# Room 1





# Room 1

| Piece of Furniture | Quantity | Dimensions (in) | Total Surface Area ($in^2$) |
|---|---|---|---|
| Bookcase | 2 | 38 x 14 | 1064 |
| Sofa | 1 | 57 x 33 | 1881 |
| Chair | 4 | 30 x 30 | 3600 |
| Round Table | 1 | 30 D | 706.86 |
| Square Table | 1 | 24 x 24 | 576 |
| Executive Chair | 1 | 22 x 18 | 396 |
| Corner Desk | 1 | 21 sq. ft. | 3024 |

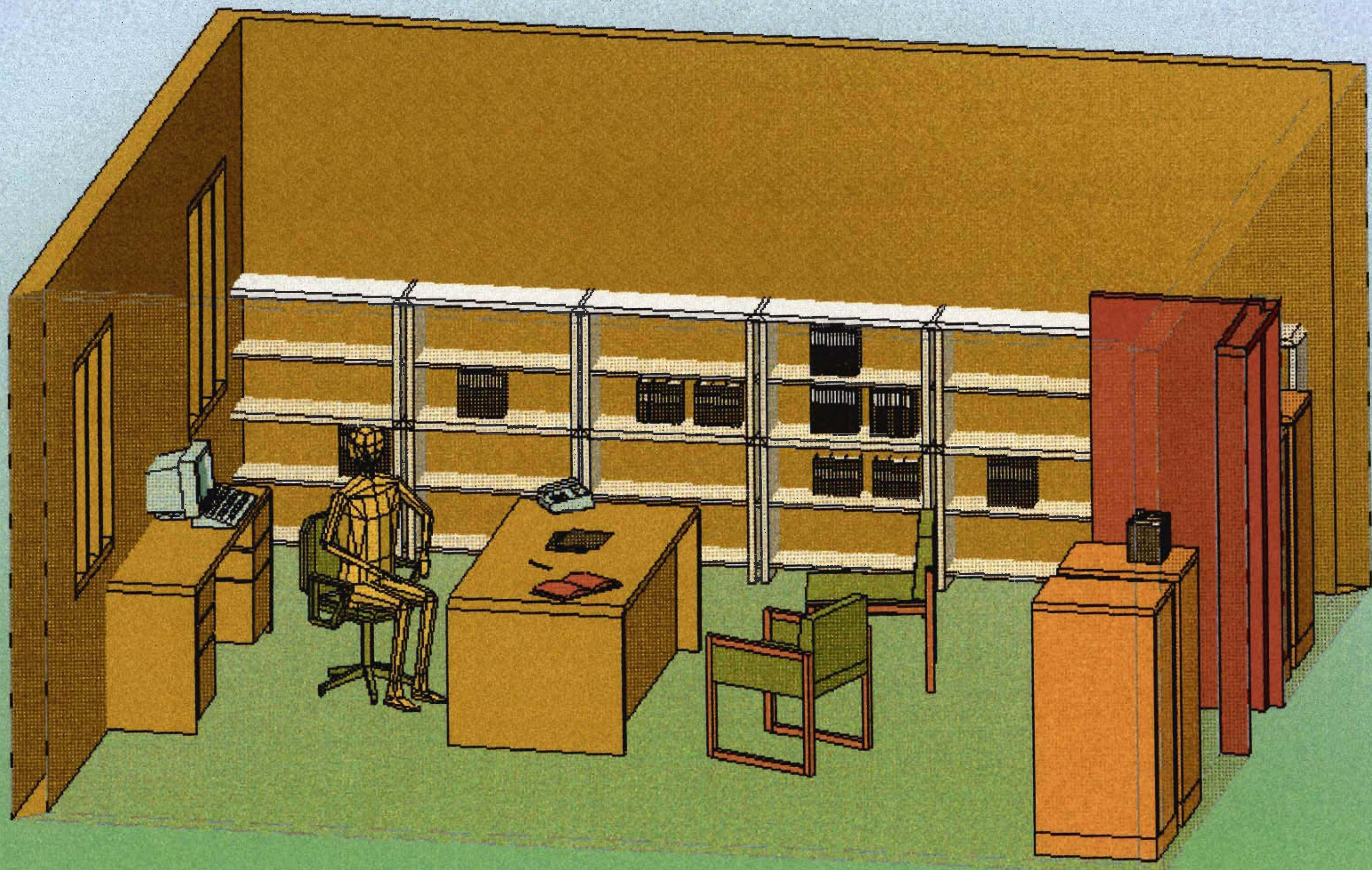
Furniture Surface Area = 11,247.86 $in^2$ = 78.11 $ft^2$

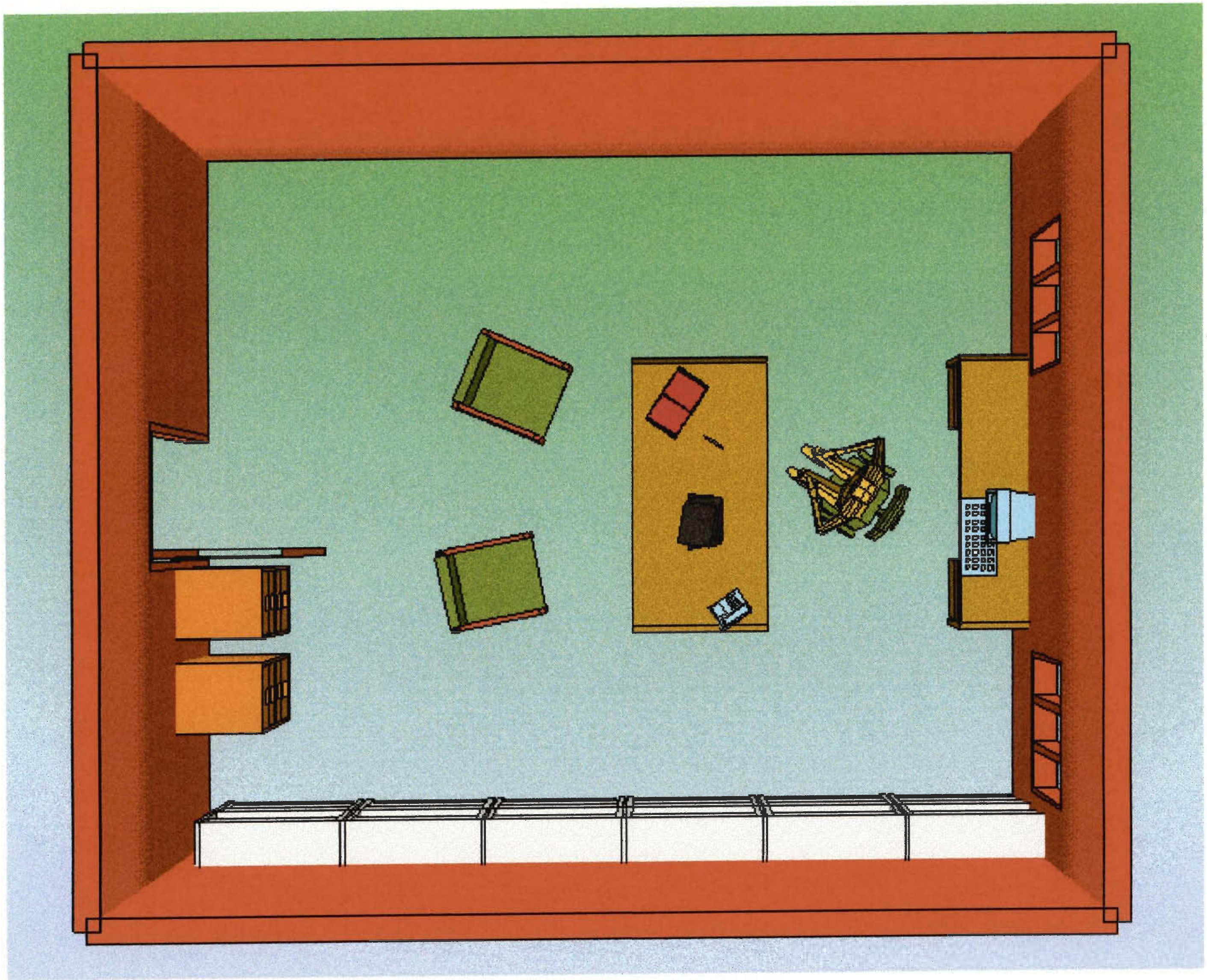
Given Room Floor Area = 25 ft. x 15 ft. = 375 $ft^2$

Furniture/Floor space ratio = 78.11 $ft^2$/375 $ft^2$ = 0.208

| If Room Dimensions are Changed to: | Furniture/Floor Space Ratio Becomes: |
|---|---|
| 20 x 15 | 0.260 |
| 20 x 10 | 0.391 |
| 15 x 15 | 0.347 |
| 25 x 20 | 0.156 |

## Room 2





# Room 2

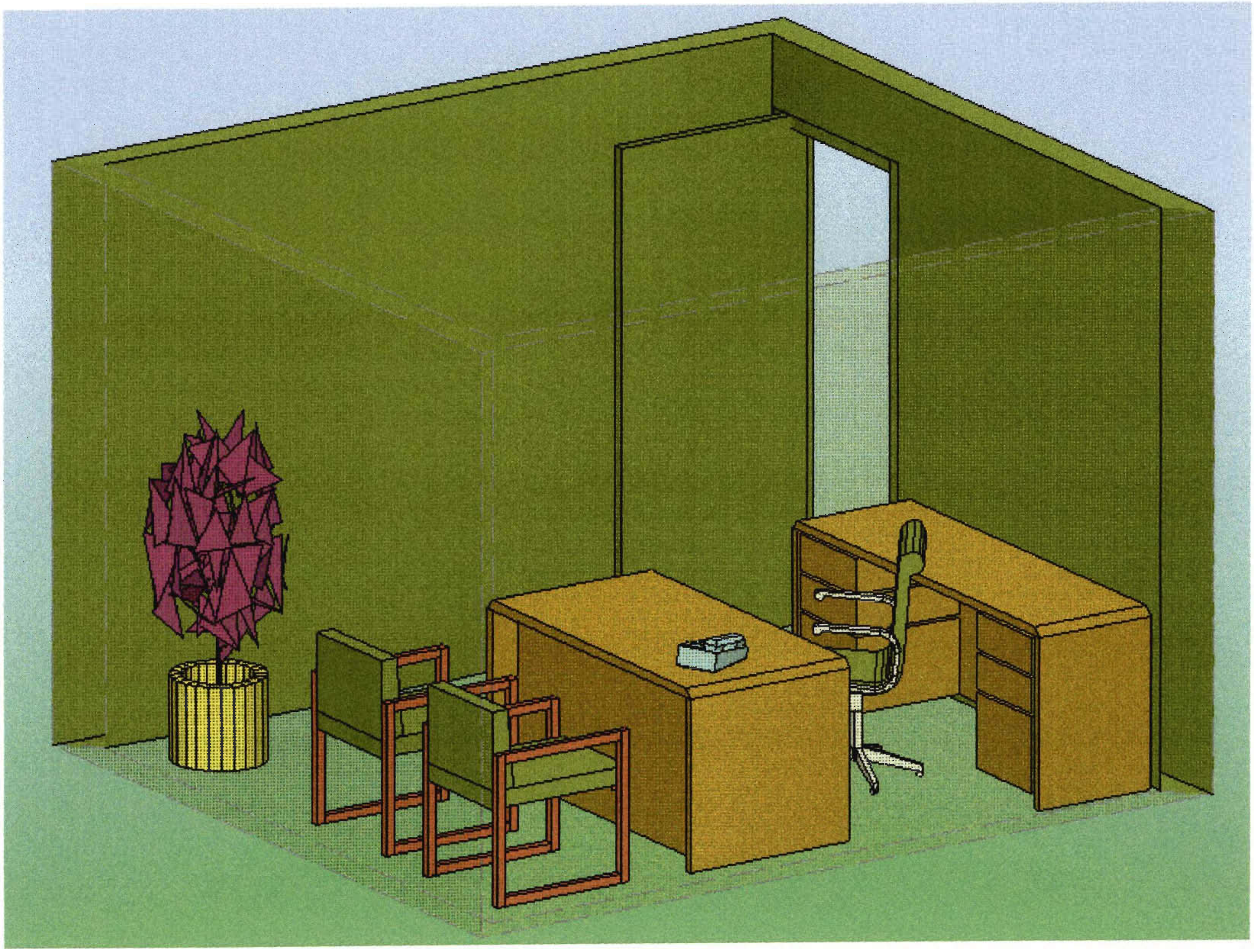
| Piece of Furniture | Quantity | Dimensions (in) | Total Surface Area ($in^2$) |
|---|---|---|---|
| Bookcase Unit | 1 | 12 x 228 | 3456 |
| Filing Cabinet | 2 | 24 x 17 | 816 |
| Chair | 2 | 25 x 22 | 1100 |
| Desk | 1 | 72 x 36 | 2592 |
| Credenza | 1 | 72 x 21 | 1512 |
| Executive Chair | 1 | 22 x 18 | 396 |

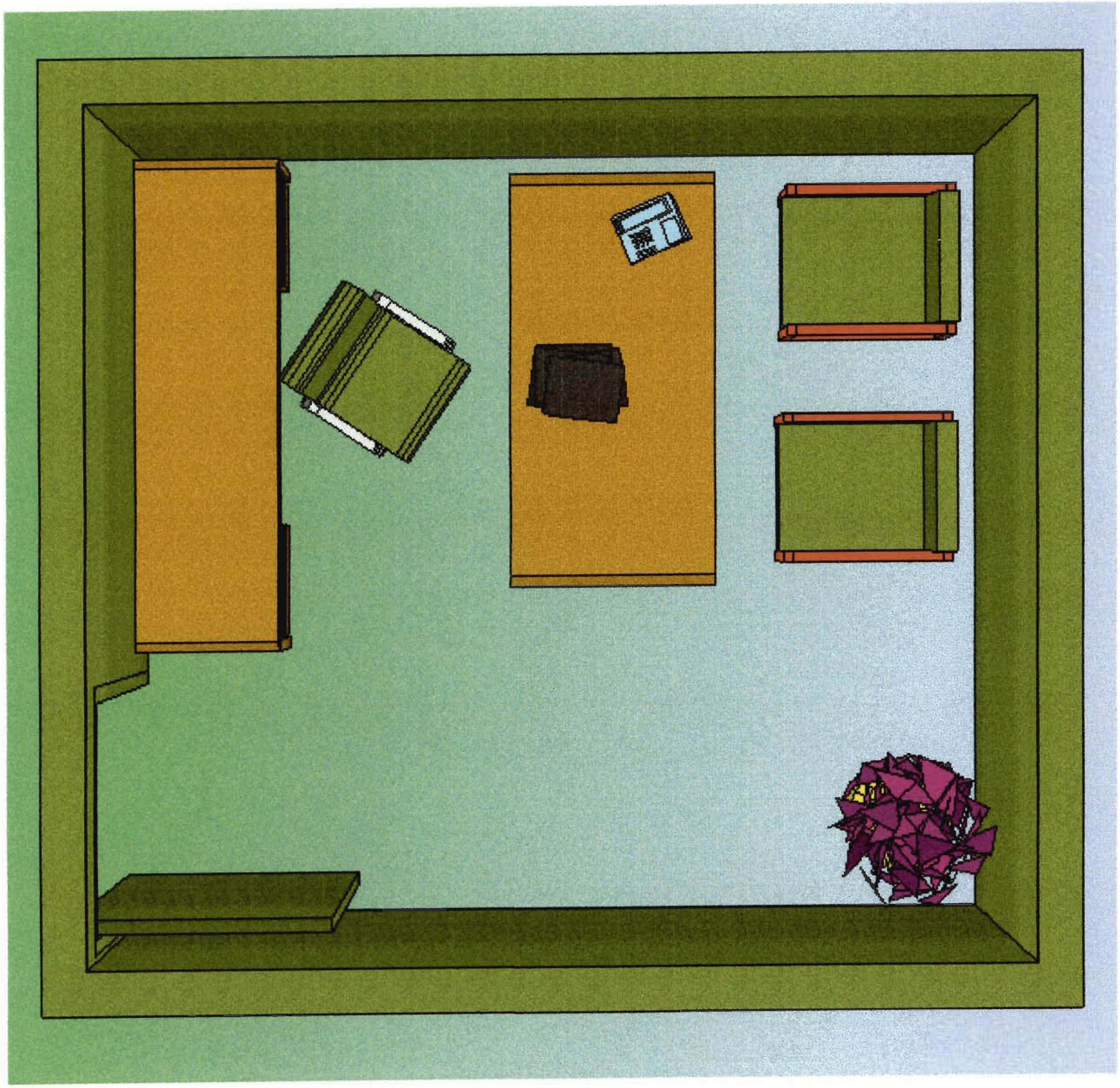
Furniture Surface Area = 9872 $in^2$ = 68.56 $ft^2$

Given Room Floor Area = 16 ft. x 19 ft. = 304 $ft^2$

Furniture/Floor space ratio = 68.56 $ft^2$/304 $ft^2$ = 0.226

| If Room Dimensions are Changed to: | Furniture/Floor Space Ratio Becomes: |
|---|---|
| 15 x 10 | 0.457 |
| 15 x 15 | 0.305 |
| 10 x 10 | 0.686 |
| 20 x 20 | 0.171 |





# Small Office

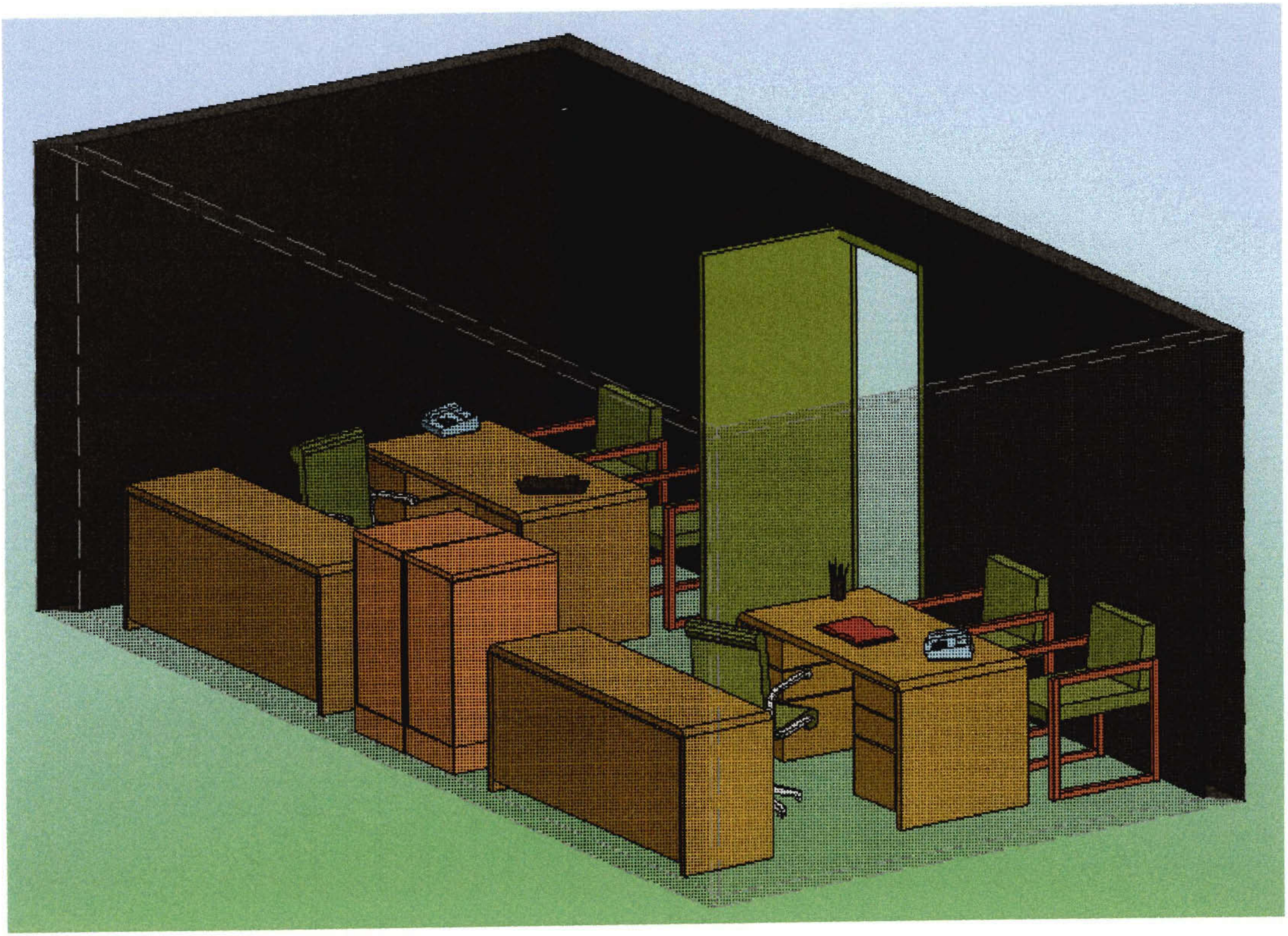
| Piece of Furniture | Quantity | Dimensions (in) | Total Surface Area ($in^2$) |
|---|---|---|---|
| Sled Base Chair | 2 | 25 x 22 | 1100 |
| Desk | 1 | 60 x 30 | 1800 |
| Credenza | 1 | 72 x 21 | 1512 |
| Executive Chair | 1 | 22 x 18 | 396 |

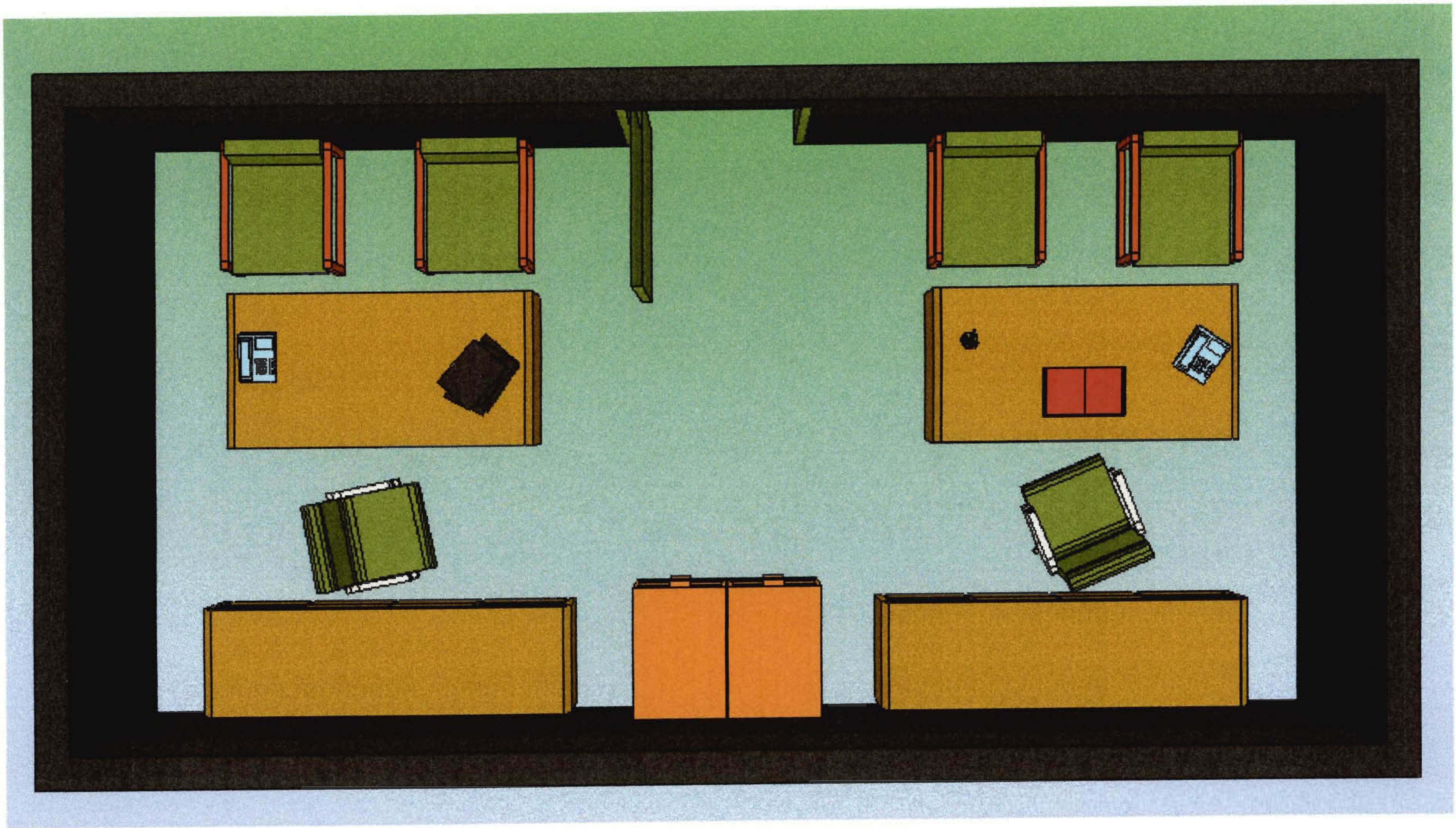
Furniture Surface Area = 4808 $in^2$ = 33.36 $ft^2$

Given Room Floor Area = 10 ft. x 11 ft. = 110 $ft^2$

Furniture/Floor space ratio = 33.36 $ft^2$/110 $ft^2$ = 0.303

| If Room Dimensions are Changed to: | Furniture/Floor Space Ratio Becomes: |
|---|---|
| 10 x 8 | 0.417 |
| 8 x 8 | 0.521 |
| 15 x 10 | 0.222 |
| 15 x 15 | 0.148 |





# Medium Office

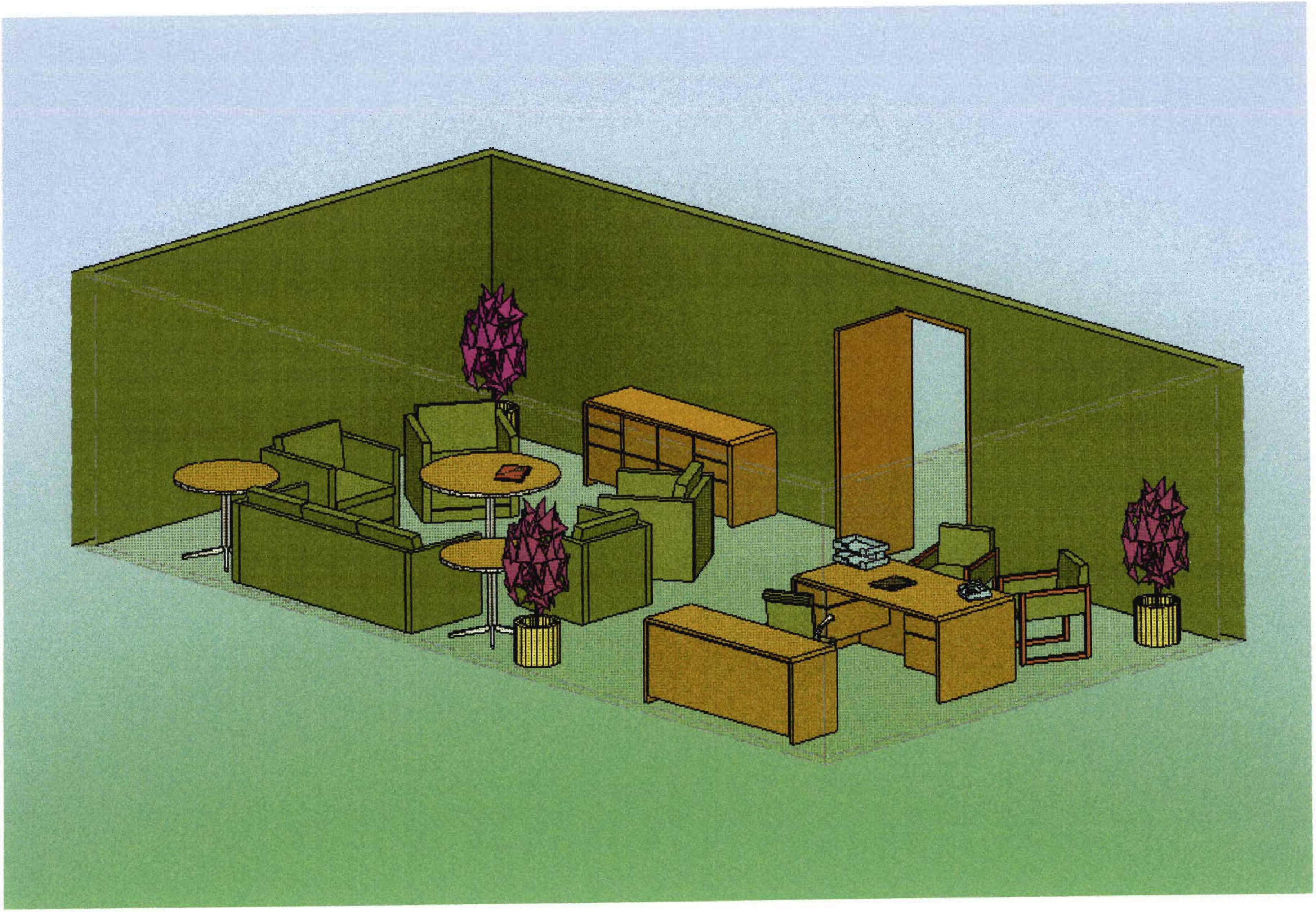
| Piece of Furniture | Quantity | Dimensions (in) | Total Surface Area ($in^2$) |
|---|---|---|---|
| Credenza | 2 | 72 x 21 | 3024 |
| Desk | 2 | 60 x 30 | 3600 |
| Sled Base Chair | 4 | 25 x 22 | 2200 |
| Executive Chair | 1 | 22 x 18 | 396 |

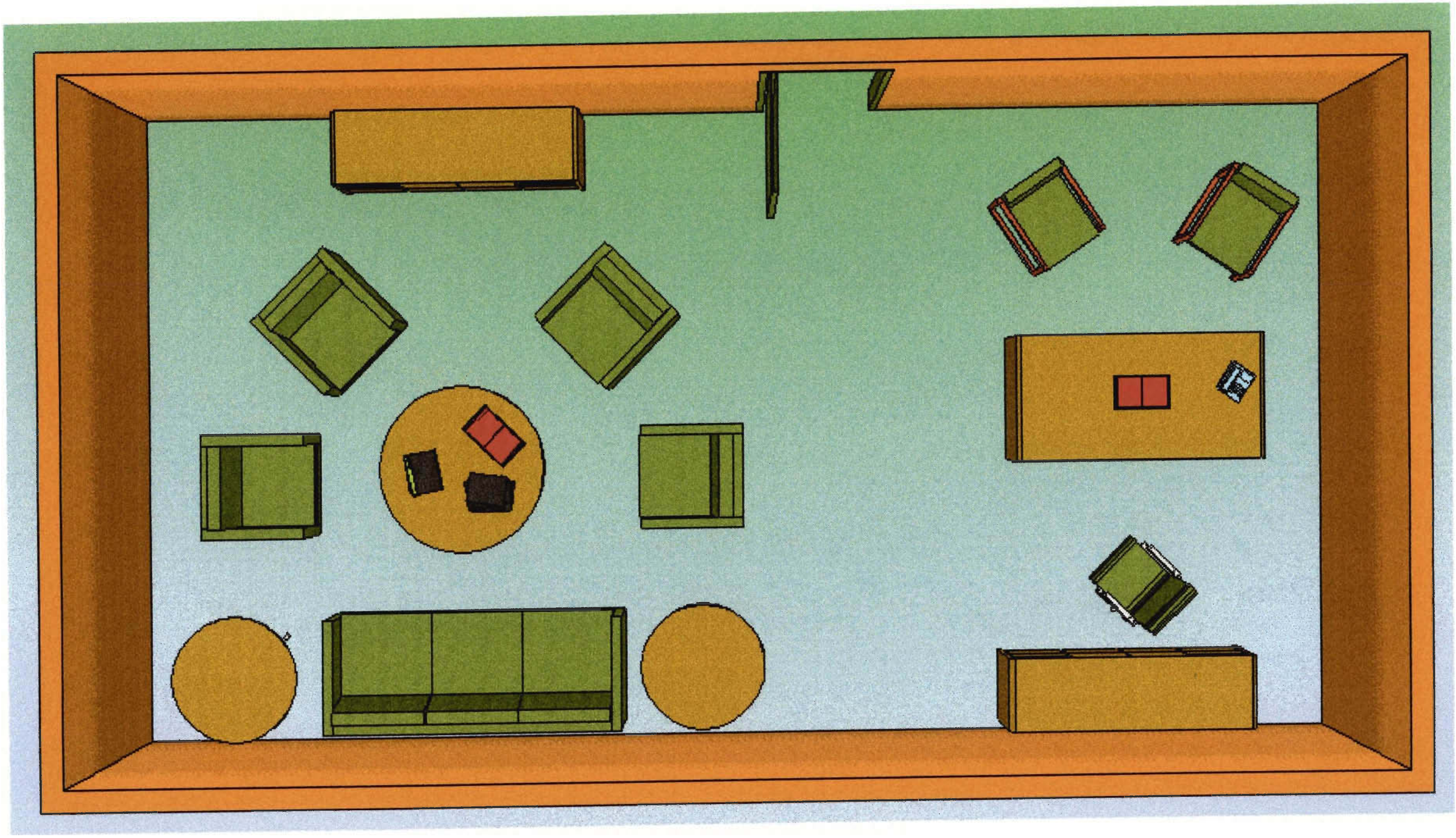
Furniture Surface Area = 9616 $in^2$ = 66.78 $ft^2$

Given Room Floor Area = 20 ft. x 10 ft. = 200 $ft^2$

Furniture/Floor space ratio = 66.78 $ft^2$/200 $ft^2$ = 0.333

| If Room Dimensions are Changed to: | Furniture/Floor Space Ratio Becomes: |
|---|---|
| 15 x 10 | 0.445 |
| 10 x 10 | 0.668 |
| 20 x 15 | 0.223 |
| 20 x 20 | 0.167 |





# Large Office

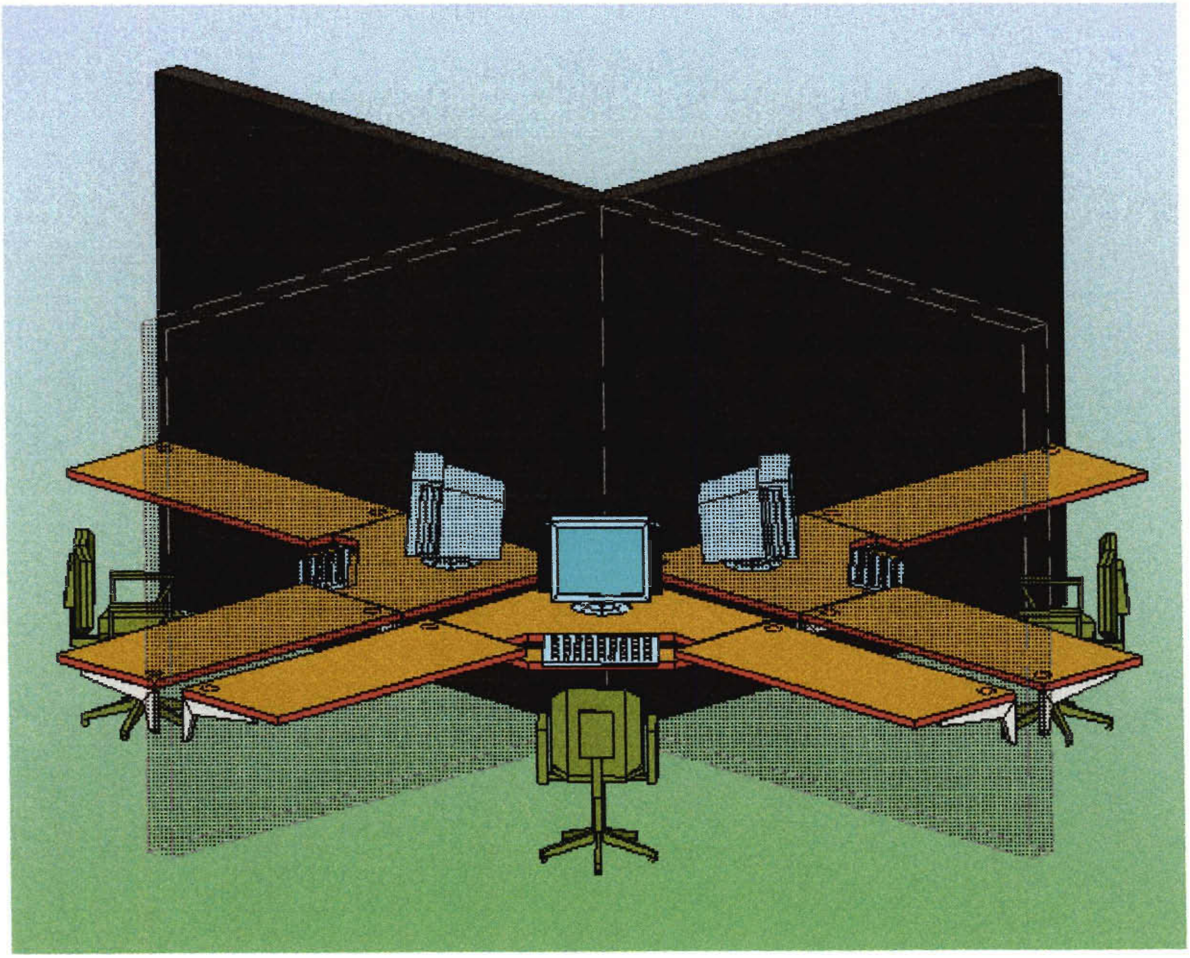
| Piece of Furniture | Quantity | Dimensions (in) | Total Surface Area ($in^2$) |
|---|---|---|---|
| Credenza | 2 | 72 x 21 | 3024 |
| Sofa | 1 | 87 x 33 | 2871 |
| Sled Base Chair | 2 | 25 x 22 | 1100 |
| Lg. Round Table | 1 | 48 D | 1809.6 |
| Sm. Round Table | 2 | 36 D | 2035.8 |
| Executive Chair | 1 | 22 x 18 | 396 |
| Chair | 4 | 30 x 30 | 3600 |
| Desk | 1 | 72 x 36 | 2592 |

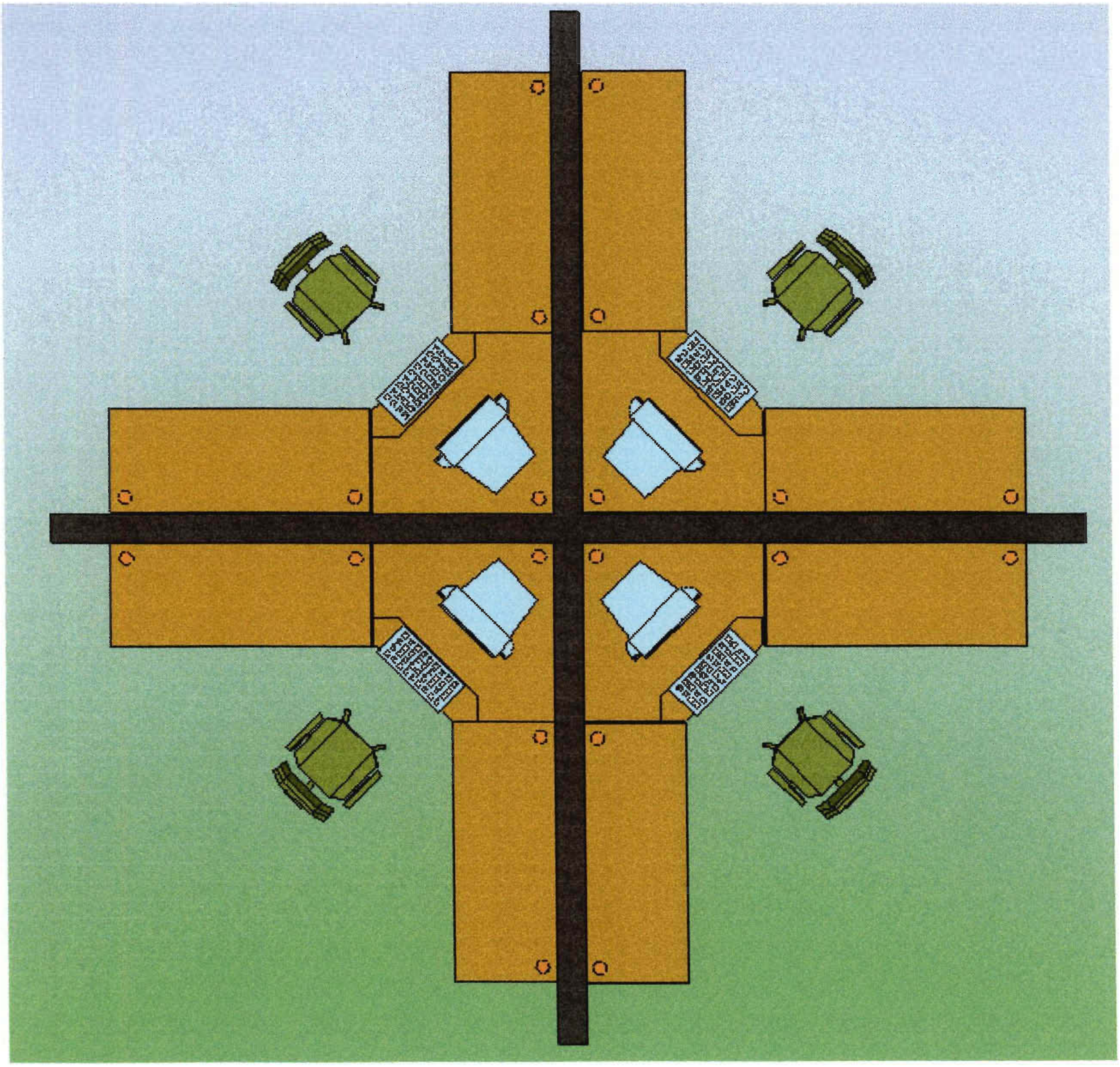
Furniture Surface Area = 17,428.9 $in^2$ = 121.03 $ft^2$

Given Room Floor Area = 30 ft. x 16 ft. = 480 $ft^2$

Furniture/Floor space ratio = 121.03 $ft^2$/480 $ft^2$ = 0.250

| If Room Dimensions are Changed to: | Furniture/Floor Space Ratio Becomes: |
|---|---|
| 25 x 15 | 0.323 |
| 20 x 15 | 0.403 |
| 30 x 30 | 0.134 |
| 30 x 25 | 0.161 |





# Open Office

| Piece of Furniture | Quantity | Dimensions (in) | Total Surface Area ($in^2$) |
|---|---|---|---|
| Work Surfaces | 8 | 60 x 24 | 11520 |
| Executive Chair | 4 | 22 x 18 | 1584 |
| Corner Desk | 4 | 42 x 24 | 4032 |

Furniture Surface Area = 17,136 $in^2$ = 119 $ft^2$

Given Room Floor Area = 20 ft. x 20 ft. = 400 $ft^2$

Furniture/Floor space ratio = 119 $ft^2$/400 $ft^2$ = 0.298

| If Room Dimensions are Changed to: | Furniture/Floor Space Ratio Becomes: |
|---|---|
| 20 x 15 | 0.397 |
| 20 x 10 | 0.595 |
| 25 x 20 | 0.238 |
| 25 x 25 | 0.190 |

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