AIRBORNE TRANSMISSION VIA HVAC OF ACUTE RESPIRATORY INFECTIONS IN MILITARY FACILITIES?
Review of a Basic Training Cohort Study

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ABSTRACT
There is great interest in preventing the spread of acute respiratory infections (ARI) in military housing and in other facilities with multiple occupants such as hospitals. There has been some research on the mode of transmission of ARIs in these types of occupancies, with several studies focusing on direct and indirect contact. This study, based on several barracks at the largest basic training facility for the Army in the United States, investigates the role of airborne transmission via heating, ventilating and air conditioning (HVAC) systems as compared to a combination of airborne, indirect contact and direct contact transmission in a room. The results indicate that there is a significant increase in the number of cases which might be attributable to airborne transmission via HVAC systems in several situations, both for ARIs that required hospitalization, and those which did not.

KEY WORDS
indoor air quality, HVAC, acute respiratory infections

INTRODUCTION
The spread of acute respiratory infections (ARI) is of great concern in the United States population, especially during certain seasons, due to its impact on loss of time at work or school, and associated medical costs (Monto 1994, Fendrick 2001, Fendrick et al. 2003). More severe cases such as febrile acute respiratory diseases (ARD), defined by having acute respiratory infection symptoms and fever greater than 100.5 degrees Fahrenheit, require isolation from apparently healthy populations. Severe cases can require hospitalization, or may even cause permanent impairment or death (Thompson et al. 2003). This is of particular concern in the military because maintaining a healthy, well-trained force is required to accomplish its mission. Higher rates of many acute respiratory infections are found in military trainee populations. Controlling ARIs in densely populated military settings is a significant challenge (Amundsen and Weiss 1994).

There are many different pathogens which can cause ARIs and there are many variables that impact their spread. These variables include age, general health, stress level and the amount and type of contact with other people. In the case of the military, there are unique variables which have been associated with an increase in the spread of ARIs. Two of these are the close quarters in military housing and the stress level on the personnel during intensive training or exercises (Wenzel et al. 1971, Brundage et al. 1988, White 2004). Learning how military housing arrangements and heating, ventilating and air conditioning (HVAC) systems used in military buildings impact the spread of ARIs is of interest to the military, and may have implications for other settings where large numbers of susceptible individuals may congregate.

A recent study was performed at Fort Jackson in Columbia, SC, on the spread of infectious diseases during basic training (White 2004). Fort Jackson is considered to be a very important test site as it is the largest Army basic combat training facility in the United States and one of only two that are gender integrated (DOD 2000). The basic combat training

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program there is similar to other training programs throughout the United States military (DOD 2003). Thus, the research findings from Fort Jackson could be representative of other military training sites.

The study by White (2004) investigated the rates of clinically diagnosed ARI cases (CD) and medical quarters admission ARI cases (MQA) over a four-month period in a population undergoing basic combat training at Fort Jackson. CD cases are afebrile and the personnel returned to their units on the day of their diagnosis, while personnel with febrile MQA cases are removed from their training unit for at least one day. This study investigated many factors that could impact the risk of acquiring an acute respiratory infection, such as the number of persons in a room in a barrack, the person's bunk location in that room, the week of training, and other personal factors such as past smoking habits and number of individuals living in their household immediately prior to joining the Army.

There have been many studies in the past about the modes of spreading these types of infectious diseases (Monto 2002, Roy and Milton 2004). Typically, respiratory infections are thought to be spread by three main modes of transfer: direct contact, indirect contract and airborne transmission. Direct contact is when an infected person either touches or coughs directly on to another person. Indirect contact is when an infected person either coughs or touches other surfaces which then come in contact with another person. Airborne transmission is when small pathogens or infected particles remain airborne, or become airborne and eventually are breathed in by others. Understanding the modes by which ARIs spread is important for developing methods for prevention and for designing facilities with lowered risk. However, determining the relative importance of these modes is very challenging. For instance, airborne pathogens might be inhaled (airborne transmission), but might also contaminate surfaces resulting in indirect transmission (Monto 2002). In the referenced study at Fort Jackson, it is obvious that an increase in the number of persons living within the same room should increase the potential for any of the three modes of transmission.

The question on how much each of the three modes contributes in the various possible scenarios is of interest and has not been resolved in many cases. Much of the focus in prevention has been with respect to the two contact modes and not the airborne mode of transmission. The purpose of this study is to evaluate if there may be a significant contribution to the spread of ARIs in these types of settings via the airborne pathway. One additional reason to focus on airborne transmission is that the smaller particles/pathogens are those most likely to remain airborne, and are also those most likely to be deposited more deeply within the human respiratory system (De Nevers 2000). Particles deposited in the deep lung are not as effectively cleared and therefore would be of greater concern.

If airborne transmission significantly contributes to the spread of ARIs, there is the potential for these airborne pathogens to be spread from space to space by way of HVAC systems. This potential would indicate that there is a need for further research and development with respect to HVAC systems and the ARI pathogens in order to decrease the spread of acute respiratory diseases in military housing, as well as other facilities with numerous occupants such as hospitals, office buildings and schools.

METHODOLOGY

The data in the study by White (2004) was taken from a group of soldiers undergoing basic combat training at Fort Jackson from February to May 2004, and included both men and women between the ages of 17 and 41 years (43% of the trainees at Fort Jackson are women). The soldiers were of many races and ethnicities. The rates of clinically diagnosed ARI cases (CD) and medical quarters admission ARI cases (MQA) were collected using hospital ICD-9 diagnosis codes over this four-month period. Environmental data such as carbon dioxide concentration, relative humidity, and distance between bunks were collected in buildings. Demographic data were self reported by trainees who signed informed consent forms and volunteered to participate in the study. White performed several statistical analyses on the rates of CD and MQA cases with respect to several independent variables including the number of bunks in a room and demographic/personal data such as past smoking habits. The analyses were further analyzed by gender. Although some information on the HVAC systems was contained in the work by White, analyses were not performed with respect to different HVAC configurations.

Of interest in this current analysis is the relationship between barrack type and HVAC configuration to the incidence rates of these upper respiratory infections, and the possible influence of airborne transmission on these rates. Two variables of particular interest are the *average room occupancies* in each barracks type and the *average contact population in the HVAC configuration. Average room occupancy* is a variable White also analyzed. It represents the average number of bunks in a dormitory room in a particular barrack type. *The average contact population in the HVAC configuration* (HVAC contact population) is the unique independent variable further analyzed here. It represents the sum of the dormitory room occupancies which share return air from multiple rooms that is mixed together in the HVAC system and distributed back to rooms as supply air. The average room occupancy is a variable which may have an impact on all three modes of transmission within a single dormitory room. The HVAC contact population is the population of people who may also contact an ARI via an additional airborne mode of transmission related to the HVAC system, especially if it is greater than the average dormitory room population, i.e. supply air contains return air from more than one dormitory room.

The three barrack/HVAC types studied had the following characteristics:

New Starship with Retrofitted HVAC

- There were four such barracks in the study.
- Each barrack had two 'pods' which would house a typical military unit of approximately 240 trainees (design occupancy).
- Each pod was a separate wing in the barrack.
- Each pod had four separate dormitory rooms with design occupancies of 60.
- During the study each the dormitory rooms in these barracks had a median occupancy of 55 (SD = 4.56, Maximum = 64, Minimum = 28).
- There were two HVAC systems which were not independent of each other and which combined return air from all four of the 60-person dormitory rooms in each pod and associated support rooms.
- The returns were ducted with VAV (variable air volume) boxes.
- There was upgraded filtration (two-stage, both 30% and 90–95%) for each pod.
- The HVAC system could either heat or cool all year round and would switch modes based on interior temperatures.
- Air flow patterns were dependent on CO_2 monitors in the dormitory rooms and would mix fresh air and return air based on these levels.
- The dormitory rooms were more air-tight to increase energy efficiency. Of particular note were the windows which were designed not to be opened by the occupants.

Old Starship

- There were two such barracks in the study.
- Each barrack had six 'pods' which would house a typical military unit of approximately 240 trainees (design occupancy).
- Each pod was a pair of separate wings in the barrack.
- Each pod had four separate dormitory rooms with design occupancies of 60.
- During the study each the dormitory rooms in these barracks had a median occupancy of 53 (SD = 10.88, Maximum = 69, Minimum = 30).
- There were two HVAC systems which were independent of each other and separately serviced one of the two wings in each pod. Each of these HVAC systems combined return air from the two 60-person dormitory rooms in each wing and associated support rooms.
- There were single-stage 30%-efficiency filters for each system.
- The HVAC systems operated in either heating mode or cooling mode which were set based on the outside weather conditions.
- The HVAC systems operated based on thermostat sensors.
- The windows could be opened by the occupants.

3-Story Brick (Rolling Pin design)

- There were ten such barracks in the study.
- Each barrack would house a typical military unit of approximately 250 trainees (design occupancy).
- Each barrack had thirty 8-person dormitory rooms and some 2 and 4 person dormitory rooms at the ends.
- During the study each of the dormitory rooms in these barracks had a median occupancy of 7 (SD = 1.03, Maximum = 8, Minimum = 4).

- There were two different HVAC system configurations and all operated independently of each other. Some of these barracks had one HVAC system for one half of the building, including half of the dormitory rooms and some shared office space on the first floor. Some of these barracks had one HVAC system for half of each floor. The second and third floor systems serviced half of the dormitory rooms on each floor respectively. Each of these HVAC systems combined return air from the dormitory rooms that it serviced.
- There were single-stage 30%-efficiency filters for each system.
- The HVAC systems operated in either heating mode or cooling mode which were set based on the outside weather conditions.
- The HVAC systems operated based on thermostat sensors.
- The windows could be opened by the occupants.
- Supply air is provided in each room with return air going into a central hallway on that half of the building where it is vented at each end of the building. Showers and toilets are located in the center of each floor. Only the second and third floors are used for sleeping.

The room occupancies and HVAC contact occupancy information for each type is summarized in Table 1. The dormitory rooms housed either males or females but not both simultaneously. Note that the female-occupied rooms in the starship style barracks tended to have substantially lower occupancies than the male. This was a result of the relative number of each gender in basic training and military requirements that training be gender integrated but living environments (sleeping areas and latrines) be segregated by gender. Females represented 37.5% of the study population. In the case of the starship barracks each gender integrated military training unit was given four 60-person barracks dormitory rooms. If the ratio of males/females did not easily separate into available rooms (i.e., 25 or 50 percent female), then either occupancy exceeded the 60-person capacity, or an additional room was used. In these situations investigators observed a tendency to overcrowd males.

Because the outcomes of interest were counts of the number of cases, Poisson regression was used to model this as a function of barrack type. Analyses were stratified by gender, with models adjusting for week of training. The outcomes were reported as rate ratios. Rate ratios are the adjusted ratios of incidences of either CD or MQA cases based on Poisson regression for the number of reported cases for a pair of values of an independent variable, e.g. building type. White (2004) compared these outcomes to the average dormitory room occupancies in each building type by use of these rate ratios. This analysis looks also at the average HVAC contact occupancy for each building type.

RESULTS

The rate ratios (RR) and corresponding 95% confidence intervals comparing the types of barracks in which the recruits resided are given in Tables 2 and 3 for the CD and MQA cases respectively. These results are based on 3700 total reported CD cases and 1705 reported MQA cases.

TABLE 1. Summary of Average Room and HVAC Contact Occupancies (White 2004).

Gender	Barracks	Average Room Occupancy	Average HVAC Contact Occupancy
Male	New Starship	>55*	>220**
Female	New Starship	<55*	<220**
Male	Old Starship	>53*	>106**
Female	Old Starship	<53*	<106**
Male	3 Story Brick	7	53 or 105
Female	3 Story Brick	7	53 or 105

*Female rooms tended to be less crowded.
**Female room pairings would have lower average HVAC contact occupancies than male room pairings.

DISCUSSION

Specific comparisons of barracks types, as depicted in Tables 2 and 3, can be used to address points of interest. As noted by White (2004), the new starship barracks and the 3-story brick barracks differ markedly in average room occupancies, thus increased febrile and afebrile ARI incidence rates observed in both genders indicate greater crowding in living space may be associated with greater ARI incidence. For example, Table 3 indicates that there are approximately twice as many MQA cases in any given time period in the new starship barracks than in the 3-story brick barracks. This result holds for both males and females. A similar result is seen in Table 2 for CD cases, although the relative increase in the starship barracks is smaller than for MQA cases. A similar situation occurs in the comparison of the old starship barracks to the 3-story brick barracks, but the difference is not as marked for the females. In fact, the female rate ratio for CD cases is near one, indicating a negligible difference, even with the large variation in potential direct and indirect contacts as indicated by the average room occupancies in these two barrack types.

White (2004) attributes some of this variation to the crowding levels found in the starship dormitory rooms experienced by the male trainees and also to possible variations in personal experiences between the two genders. However, as mentioned, there are also variations in the potential for airborne transmittal of ARIs between the barracks types via the HVAC systems. The new starship and old starship barracks each have approximately the same average room occupancy, but differ markedly in number of recruits contacted per HVAC system. Thus, the significant results for females at both levels of ARI indicate that greater numbers of recruits in contact with a given HVAC system is associated with greater numbers of ARIs. No such relationship was seen for males.

CONCLUSIONS

As previously noted by White (2004), these results indicate the number of trainees in a barrack room may impact the risk of both febrile and afebrile acute respiratory infection transmission. This can be seen in the data presented in Tables 2 and 3, where each of the starship barracks are compared to the older

TABLE 2. Rate Ratios of Clinically Diagnosed (CD) Afebrile ARI Cases in Barracks at Fort Jackson during Basic Training.

Gender	Barracks	Compared to	Rate Ratio	95% Confidence Interval	
Male	New Starship	3 Story Brick	1.47	1.23	1.76
Female	New Starship	3 Story Brick	1.32	1.13	1.55
Male	Old Starship	3 Story Brick	1.41	1.20	1.65
Female	Old Starship	3 Story Brick	1.07	0.88	1.29
Male	New Starship	Old Starship	1.05	0.93	1.18
Female	New Starship	Old Starship	1.23	1.05	1.46

TABLE 3. Rate Ratios of Medical Quarters Admitted (MQA) Febrile ARI Cases in Barracks at Fort Jackson during Basic Training.

Gender	Barracks	Compared to	Rate Ratio	95% Confidence Interval	
Male	New Starship	3-Story Brick	1.98	1.47	2.67
Female	New Starship	3-Story Brick	2.07	1.54	2.78
Male	Old Starship	3-Story Brick	2.05	1.56	2.70
Female	Old Starship	3-Story Brick	1.56	1.11	2.20
Male	New Starship	Old Starship	0.96	0.79	1.18
Female	New Starship	Old Starship	1.32	1.04	1.69

3-story brick barracks. The starship barracks have 60-person rooms and the older 3-story brick barracks have mainly 8-person rooms and a few rooms with fewer than 8 persons.

As studied herein, the results also suggest that there is a significant potential for airborne transmission of ARIs via the HVAC systems as can be seen in the results for the female population in Tables 2 and 3, where the new starship barracks with four-room contact via the return air in the HVAC system is compared to the old starship barracks which have HVAC systems that are dedicated to two 60-person rooms.

The second item to analyze in these results is the fact that the incident rates for the males did not appear to change significantly between the two starship barrack types which had the different levels of HVAC contact, but similar room occupancies. One reason for this might be related to the higher incidences of the direct and indirect contact modes which may have occurred for the males in both of the starship barracks in more crowded room conditions, effectively masking other less prevalent modes of transmission. For both CD and MQA cases, the rate ratios for males in the old starship barracks as compared to the 3-story brick barracks are much higher than for the females, and nearly identical to the rate ratios for the males comparatively between the two starship types. As previously noted, the males in the old and new starship barracks are, on average, more crowded than the females in the rooms. With this higher occupancy, it is reasonable to assume that there are more opportunities for direct and indirect contact transmission of the ARIs. Therefore, the impact of the airborne transmission via the HVAC system may be masked by the higher number of potential contact transmissions in the rooms.

In summary, previous studies indicate that dormitory occupancies can affect the incidence rates of both afebrile and febrile ARI cases, which can reasonably be explained by greater levels of direct, indirect and airborne transmission within the rooms. Here, in buildings with similar room occupancies, it was found that higher incidence rates were associated with additional opportunities for airborne transmission via the HVAC system design, which indicates that HVAC system design may affect ARI rates. The differences in the HVAC systems compared included additional contact via supply air and also some variations in ventilation rates with occupant access to operable windows. The higher rates were experienced in the systems with both higher HVAC contact occupancies and less access to operable windows.

RECOMMENDATIONS

This study's purpose is to see whether HVAC system modifications in military housing may potentially improve the indoor air quality and decrease transmission of ARIs among individuals living in crowded environments. The results indicate that there is indeed a significant risk of airborne ARI transmission through HVAC systems and HVAC system improvement should be investigated.

There are several methods that can be used to improve indoor air quality. Three main approaches are:

- Increase in the outdoor air exchange rate to replace contaminated air with outside air containing fewer human pathogens.
- Improve filtration in HVAC systems to remove more particulate matter (PM), which can contain many pollutants including pathogens.
- Other methods to destroy, remove or prevent the spread of pathogens in HVAC systems.

An increase in the outdoor air exchange rate and the use of filtration in HVAC systems are common methods for prevention of pathogen airborne transmission via the HVAC systems. However, both typically require an increase in energy use, and filtration techniques usually require a certain level of maintenance for prolonged efficacy. Therefore, it may be advantageous to investigate alternative methods of preventing the spread of airborne pathogens via HVAC systems. The intent of the analyses presented was to estimate the overall impact that improvements in the HVAC system may have on the spread of ARIs via airborne transmissions.

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