Science of the Total Environment 569–570 (2016) 373–381

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Potential impact of a ventilation intervention for influenza in the context of a dense indoor contact network in Hong Kong

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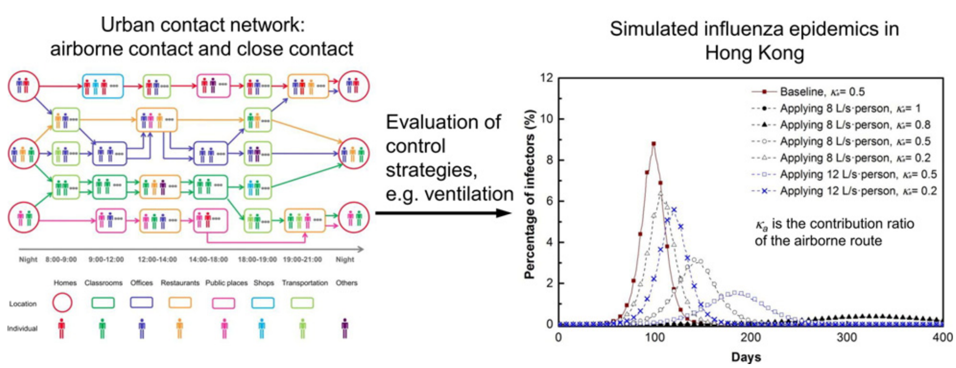
HIGHLIGHTS

- A dual-contact (close contact and airborne contact) network was constructed.
- Effect of control strategies was evaluated at the community level.
- Important role of building ventilation in influenza control was revealed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 April 2016
Received in revised form 21 June 2016
Accepted 21 June 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Building ventilation
Urban contact network
Influenza
Partially airborne route

ABSTRACT

Emerging diseases may spread rapidly through dense and large urban contact networks. We constructed a simple but novel dual-contact network model to account for both airborne contact and close contact of individuals in the densely populated city of Hong Kong. The model was then integrated with an existing epidemiological susceptible-exposed-infectious-recovered (SEIR) model, and we used a revised Wells-Riley model to estimate infection risks by the airborne route and an exponential dose-response model for risks by the contact and droplet routes. A potential outbreak of partially airborne influenza was examined, assuming different proportions of transmission through the airborne route. Our results show that building ventilation can have significant effects in airborne transmission-dominated conditions. Moreover, even when the airborne route only contributes 20% to the total infection risk, increasing the ventilation rate has a strong influence on transmission dynamics, and it also can achieve control effects similar to those of wearing masks for patients, isolation and vaccination.

1. Introduction

The recent 2003 SARS epidemics, the 2009 H1N1 pandemic and the 2015 MERS epidemics have highlighted the importance of studying respiratory activities (Yu et al., 2004; Scalera and Mossad, 2009; Zumla et al., 2015). Most respiratory infections are generally believed to be

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http://dx.doi.org/10.1016/j.scitotenv.2016.06.179

transmitted through multiple routes (Jefferson et al., 2009; Cowling et al., 2010; Li et al., 2007). Although various definitions exist in the literature, three routes of respiratory disease transmission are primarily acknowledged: droplet transmission, indirect contact transmission and airborne transmission (e.g., Brankston et al., 2007). The contribution of the airborne route in influenza virus, chickenpox and the common cold, however, is still controversial (Tellier, 2006 and 2009). The relative effectiveness of different administrative and personal control methods has been well studied to a certain degree using general public health methods (e.g., Riley et al., 2003; Ferguson et al., 2006). However, studies of the relative effectiveness of engineering control at the community level are rare, possibly due to the difficulties of distinguishing transmission routes. Roles of ventilation, ultraviolet germicidal irradiation and filtration were studied using the so-called Wells-Riley equation (Riley et al., 1978; Beggs and Sleigh, 2002; Seppanen et al., 1999) in a single room.

Building ventilation is known to be effective in reducing the spread of airborne diseases (WHO, 2007 and 2009). Previous work has shown that ventilation can reduce exposure to airborne infectious agents by directing the flow of airborne infectious agents away from susceptible persons and/or by removing airborne infectious agents from room air, thus mitigating epidemics of infectious diseases transmitted through the airborne route (e.g., Noakes et al., 2006; Gao et al., 2009). Ventilation was found to be associated with the transmission of diseases such as tuberculosis, SARS, smallpox, chickenpox and influenza (Li et al., 2007). Control of ventilation has an advantage over other non-pharmaceutical interventions (e.g., hand washing or mask use) because it relies less on individual compliance. A significant knowledge gap, however, persists with respect to the effects of ventilation at the community level on infectious diseases transmitted through multiple routes (Brankston et al., 2007; Tellier, 2006 and 2009). The effectiveness of ventilation in controlling fully airborne-transmitted diseases has been evaluated in a single indoor environment (Beggs et al., 2003; Noakes and Sleigh, 2009) or roughly estimated in a community (Gao et al., 2009), but it has not been studied with consideration of social contact patterns and possible existences of other routes. Ventilation may not affect the exposure of susceptible persons to infectious agents through droplet or contact exposure.

In a large city, people are in constant contact as they move from one indoor environment to another (see Fig. 1). Most existing non-pharmaceutical interventions are studied at the level of individual contact events, apart from Jones and Adida (2013). The individual contact and exposure in each indoor environment needs to be linked to disease transmission at the entire city level. Several social networks are available. The widely used social contact networks, e.g., the random network model (Newman, 2002), may be too simplistic to simulating disease spread at an individual level, and they do not take into account the physical dimensions (including ventilation) of the environment. In contrast, the location-based network model by Eubank et al. (2004, 2006) requires computational resources that are not available to study the spread of infection in a large city. Thus, Gao (2011) developed a simple indoor contact model based on the concept of a "connected" indoor environment and successfully simulated a fully airborne smallpox outbreak in Hong Kong.

Our objective in this paper is to evaluate the effectiveness of ventilation intervention for partially airborne influenza in a dense indoor contact network by simulating a potential outbreak of influenza in Hong Kong. First, we extend an existing indoor contact network model that can estimate the probability and duration of any two of the 7 million people in Hong Kong meeting together (airborne contact) into estimating close contact (droplet contact) in any of the approximately 3 million indoor environments (locations). This is the so-called dual-contact model. The dual contact refers to both airborne contact and close contact. Second, we develop a simple dynamic model of disease that considers the effects of building ventilation and other intervention strategies and a given relative contribution of each transmission route. Our simple developed model allows the effectiveness of an intervention to be evaluated by holding constant the airborne contribution to infection risk.

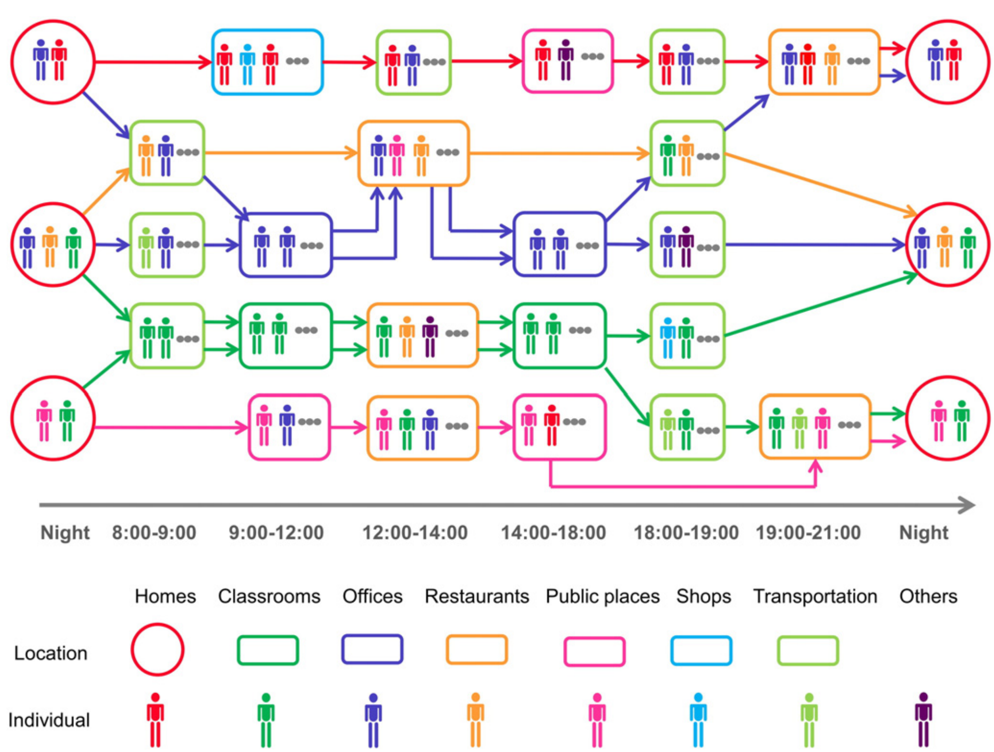

Fig. 1. Illustration of contacts of individuals. Individuals with different occupations (represented by different colors) come into contact in different types of locations (represented by different colors and shapes) during a typical workday.