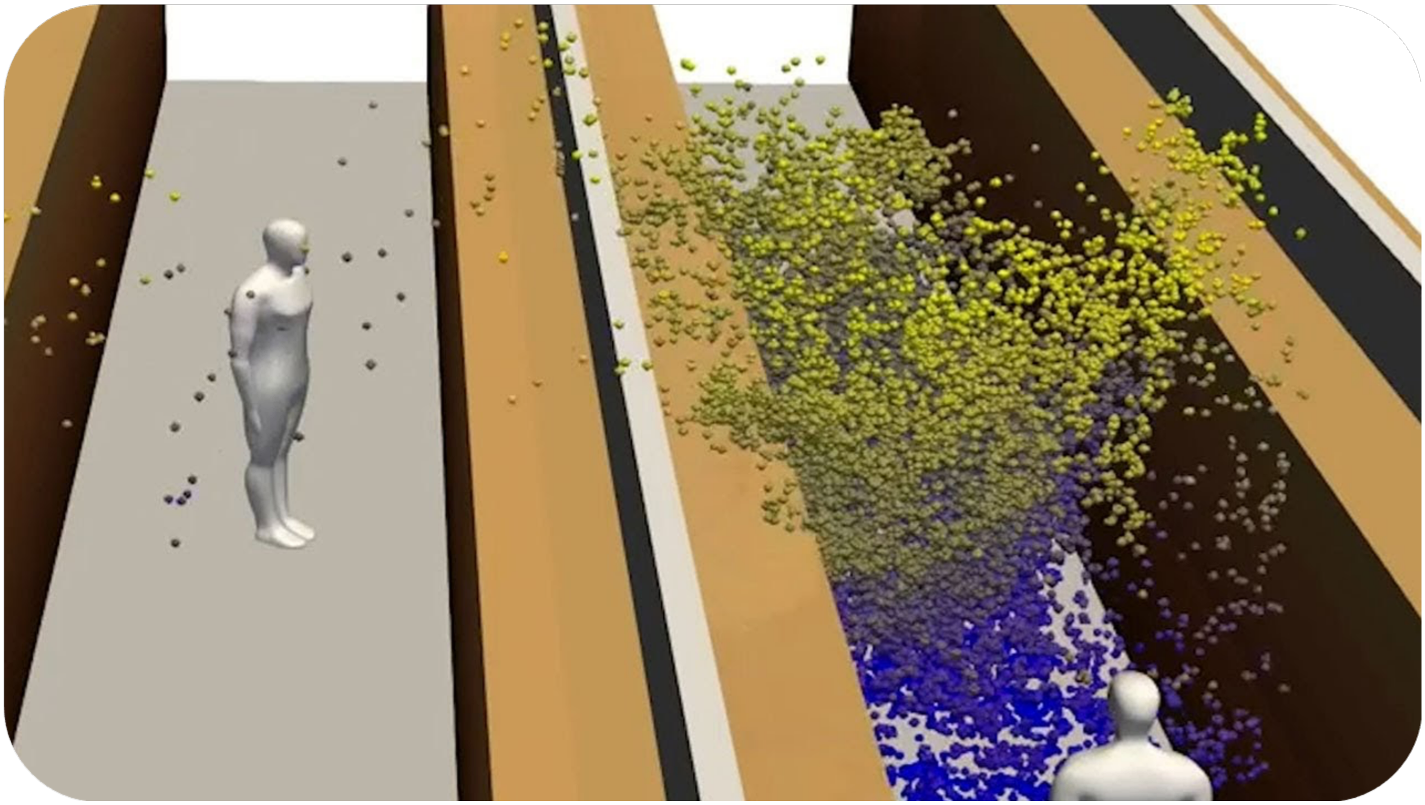

Airborne Contaminant Management Within an Indoor Environment

Challenge:	UK Azure Fundamentals Championship 2020
Challenge Topic:	Healthcare
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Institution:	University of Lincoln
Authors:	Callum Thompson - BSc (Hons) Games Computing [Year 2]
	Garry Clawson - BSc (Hons) Computer Science [Year 2]

1. INTRODUCTION

Airflow within buildings is not something that is historically thought about outside of air conditioning or heating. Once a building is designed and built, managing airflow is particularly difficult due to the static nature of the space, especially if a changing/dynamic delivery of airflow is needed.

Airborne diseases such as COVID-19 have now brought the movement of air, particularly person-to-person movement of air, to the forefront of the public's mind especially when indoors. This UK Azure Fundamentals Championship submission intends to present a solution to the management of indoor airflow to reduce COVID-19 like transmissions to mitigate this public concern. This solution will be useful in hospitals, dentists, care homes as well as wider premises such as shopping centres.

2. BACKGROUND TO PROBLEM

The Center for Disease Control & Prevention (CDC) as well as the World Health Organisation (WHO) have prepared a significant set of statistics regarding COVID-19 transmission. The two main avenues of non contact delivery are via droplet (short range) or aerosol (long range), this is circa <1.5m and >1.5 meters respectively. However, the CDC states that air convection as well as air humidity play a large part in the propagation process itself, noting that "*strong airflow from the air conditioner could have propagated droplets*" when reviewing airborne transmissions. The CDC also notes that a distance of 4m could be achieved if aerosols are generated by the use of suction or intubation in a hospital setting.

As well as the distance that an airborne disease can travel, the duration it can persist as an aerosol is stated by the WHO to be circa 3 hours. This, also coupled with a paper in the *Annual Review of Virology* entitled *Seasonality of Respiratory Viral Infections* suggests that humidity between 50% - 80% is ideal to minimize airborne proliferation of a SARS-CoV-2 type disease. The CDC also further goes on to state that once propagated, movement of airborne diseases onto surfaces (floors, bins etc) can then proceed to survive from 4 hours to 2-3 days. Minimising this transmission path is thus critical to public safety with the ability to clearly manage airborne contaminants a positive route to reducing potential infections.

The above overview shows that if it is possible to identify, move and ultimately discharge contaminated air from an internal or enclosed space as quickly, as possible or via the shortest route possible, this would be advantageous to not just the occupants but also the wider hospital operation.

3. CONCEPT OVERVIEW

Wearable technology today is ubiquitous and ranges from watches, bracelets to even personal implants. This technology has been extended to help monitor and manage a person's health and to help guide improved lifestyle choices (i.e. 10,000 steps/day challenge). However, this technology has not yet been extended to help dynamically inform the built environment around you (i.e. slow an elevator if you have a limp).

Although, just knowing what a concern is is not enough. Wearable technology needs to be able to mitigate that concern by dynamically controlling your surroundings. Localised air conditioning systems are again pervasive within indoor environments and are generally managed as part of a BMS (Building Management System). However, what they do not do is respond to a user, they only respond to the environment on a given set of parameters of which a user is set within. Further, employing localised extraction at the bedside or throughout corridors can extend the concept of managing airborne particles throughout a building infrastructure. This is without evening mentioning windows and doors.

Giving a BMS system the ability to utilise streaming data (personal & sensor) to dynamically manage a localised environment turns the current BMS idea on its head and lets the building command what resources it needs rather than the operators dictate what services the building needs.

Azure services would facilitate IoT devices and support the flow of air through a building to facilitate minimal exposure to airborne particles at any one time. They would facilitate management of when certain doors/windows are open (to what degree or speed), extraction and air conditioning speed (and timing) to mitigate any spread of a disease. Along with streaming personal data (via wearable technology) it would be possible to identify a source of contamination but also the possible spread to ensure rapid clean up where required.

Employing ML and AI into this mix also moves a static building into a dynamic building; determining what areas need the most attention (for cleaning say) and which areas do not. The current pseudo dynamic environment monitoring does not allow a distributed connected network to leverage or learn through either AI or ML (say Azure Edge devices), nor does it allow real time change due to demand changes in that environment. It just allows air conditioning to be on or off, or heating to be low, medium or high. There is no current intelligence built in.

Each of the above technologies is readably available although may not yet currently be used in the way required or linked via IoT technology. Nederman, who are the best in class air extraction manufacturers, do not yet facilitate IoT connectivity in their extraction solutions. Philips

Wearable BioSensor only currently measures vital signs, posture, step count but not a user's internal body pressure, diaphragm movement or breathing cadence which may indicate a cough or sneeze. Air conditioning systems are connected to a BMS but are generally managed in clusters or zones in a defined space, not individually managed to a local need or in response to a continually changing environment.

Linking wearable technology, air control services as well as building resources into a single theme we can begin to conceptualise how a new style of airflow management can be developed. This concept will look to provide a tangible framework of not just smart buildings but 'living buildings'.

4. USER INTERACTION

The systems will require user interaction but in a passive way. To ensure that a user can be connected to the concept a wearable device such as the Phillips Biosensor needs to be employed. This Biosensor would recognise persons orientation as well as extended features such as ability to detect a cough or sneeze. This sensor would also support GPS through Philips Internal GPS that is implemented within local ceiling mounted lights using Visible Light Communication (VLC) technology. This wearable would be connected to Azure using MQTT messaging as a standard protocol.

As a user moves throughout the building a real time environment map is constructed through the use of Digital Twins and ingested data for Stream Analytics, ML & AI technology (supported by IoT devices). This map is built up with a users' breathing rates, coughs, sneezes and general air circulation through a dynamic space. Figure 4a demonstrates a snapshot of a building where IoT devices map the airflow in real time via sensor technology. The red zones are 'high' contamination' areas and the green are 'low' contamination areas. Figure 4b shows a 3D model of a confined space and the airflow circulation. The *new* purpose of the Building Management System is to *understand* what a contaminated space is and how to move the air out as quickly as possible or perhaps, at ceiling height by creating differential pressure zones within a single space.

To avoid personnel coming into contact with any airborne particles may mean routing the air flow through the shortest space possible employing trigger Functions, Logic Apps (to manage system states), as well as ML & AI to learn new methods to ensure minimal human contact (think advanced Dijkstra or A* here built directly within a Function). The Azure Event Grid would then support the comandering of resources to rapidly deploy teams for clean up or decontamination where required. This itself increases space use efficiency and resource effectiveness.

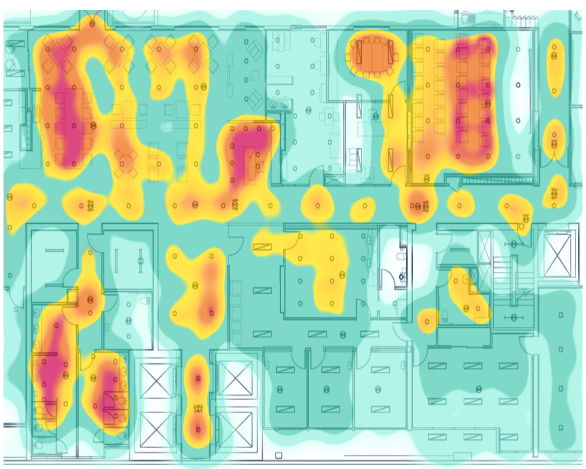

Figure 4a: Contamination Map

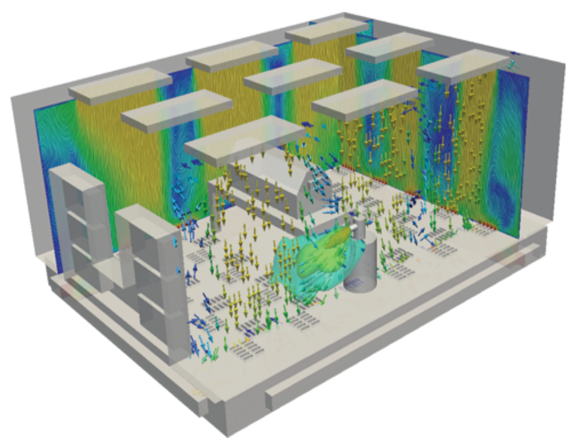

Figure 4b: Airflow Circulation Map

One result of this implementation is that a hospital building can then manage contamination concerns in real time without human intervention. This would ensure that spaces are more effectively used, all space users are more properly supported and NHS services are more available.

5. CONCEPT ARCHITECTURE DESIGN

Figure 5 details the concept architecture employed by the system. Serverless functions feedback to IoT devices with analytics managed at the front end to support automated activity and anomaly detection. Data visualization is managed through integrating HoloLens for direct user interaction (using Mixed Reality) as well as wider analysis through PowerBI. The Event Hub, Grid and Logic App take care of the operation of the system being informed by the prepared environment analysis completed by the Azure Cognitive Services as well as Computer Vision API.

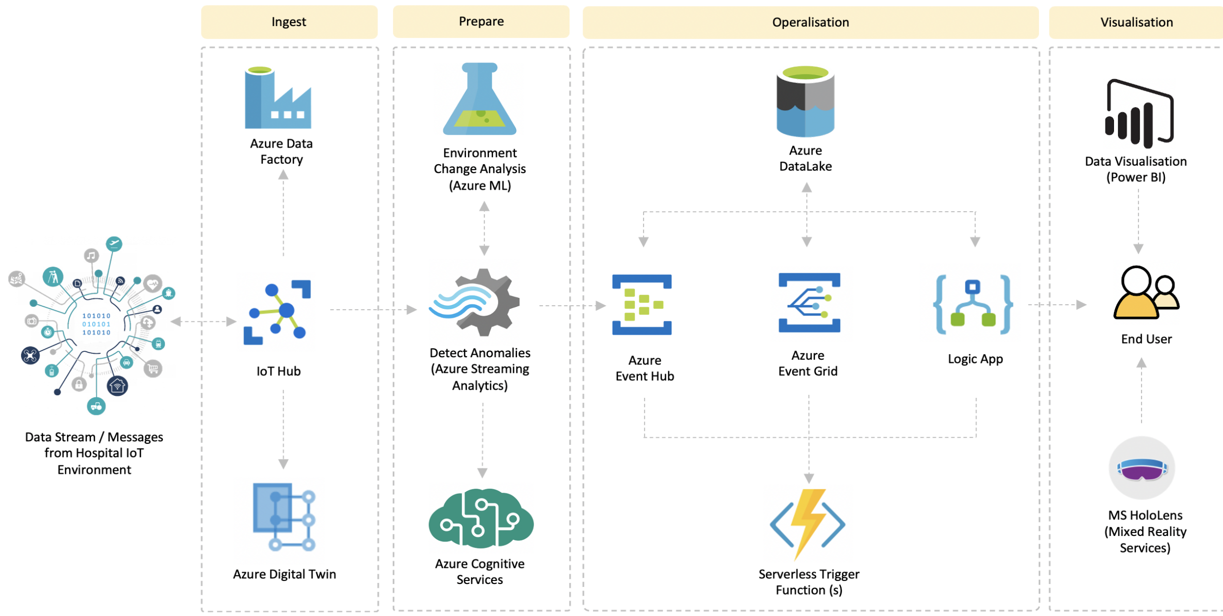

Figure 5: Architecture of the Airborne Contaminant Management concept using Azure

6. IMPLEMENTATION

The key to this concept is not complexity but extensibility. Deploying the simplest solution to manage the few key concerns will yield more immediate benefits than a deeply deployed IoT network. The Azure Digital Twin technology is deeply ingrained to support intelligence from sensor logic, continually improving the effectiveness of the hospital in real time. The below describes several resources that have been employed.

The **Azure IoT Hub** is used for ingesting large quantities of data from IoT devices in the hospital building as well as from user wearables. The IoT hub will be used to ensure the full connection of all IoT devices while being flexible, scalable and secure. The ability for the IoT hub to also push updates to devices also allows possibilities for Edge ML but more importantly being able to update firmware. The Hub will act as the central information broker from the outside world as well as linking the digital twin and Azure data factory for seamless on and off premises data storage.

The **Azure Logic App** will support the automated scheduling of tasks for each of the air conditioning devices, air extraction devices and the building fabric. The Logic App will also be able to populate a traffic lighting system to show Red/Amber/Green spaces and automatically command resources for clean up or further service requirements. This will then feed into CosmosDB and then into PowerBi via the Azure DataLake service.

Azure Cognitive Services are a key component within this concept. Azure Custom Vision is deployed to analyze any 'out of standard' spaces (i.e. beds not in the right place, equipment mispositioned etc.) to aid in determining any potential contamination threats. For instance, if a patient sneezes in an empty room ML with AI will identify the contamination zone and create the required event trigger however; if the said person then leaves the room the next user in (say a Nurse) will not know that a piece of equipment is contaminated and could put it away. Azure Cognitive Services help avoid this scenario and initiate the required response to efficiently and safely manage this situation.

Azure Machine Learning is used to optimize the management of the BMS services and continually improve the intelligence of how air flow moves within the hospital building. The ML service will be critical in enabling the fine tune controls of the air flow control systems depending on what scenario is presented (i.e. busy corridors, open windows etc.) to then manage the movement of contaminated air in the safest possible way.

The **Kinect DK** tool although not in itself an Azure app can be deeply integrated into Azure. This tool will allow the hospital staff to monitor spaces as well as build the real time visual representation of airborne contamination flow by using mixed reality through the use of Microsoft HoloLens. This can aid key workers in efficient decontamination, helping the team target their efforts for maximum effectiveness and results.

6.1 Primary Use Case of Azure Services:

The primary use case of the concept is to move air through the building to remove airborne contaminants. This is not possible by just using a simple Building Management System and air conditioning system that is not contextually aware of the environment. Using IoT with the power of Azure coupled with digital twins allows the building to become augmented into a living environment.

The monitoring of room occupation metrics is vital and this is achieved through the KinectDK linked to the Azure Cognitive Services. KinectDK allows real time visual analysis to help identify what has changed or capture where room entrants have been. Wearable BioSensor technology compliments this by allowing discrete personal data to be overlaid with the visual world. HoloLens technology can then augment low/med/high risk zones and real time airflow graphics to support the user in the real time navigation of spaces to ensure minimal possible disease exposure.

Integrated IoT devices managed via the IoT Hub with Azure ML (supported by Edge devices where required) detects a crowded space and if any anomalies are present. This allows each and every space to be monitored against a known normal (i.e. scored) and where this normal changes events via the Event Grid or Event Hub can be fired. Temperature and humidity changes can therefore be managed *on the fly* to ensure that best conditions for COVID-19 like diseases are not supported; especially in unused rooms which are not actively monitored but have been visited.

Finally, once an event has been triggered, we can begin to effectively triage and bring the space back to standard. A live building can manage its own resources using the Logic App, this means decontamination can take place 'where needed - when needed'. In an environment that is constantly changing, having a static schedule for cleanup is no longer effective or efficient. This concept turns that paradigm on its head and the 'living building' behaves similar to how an immune system creates T-Cells in the presence of an unknown body tackling where and when needed.

6.2 Secondary Use Case Focus of Azure Services

The secondary use case of the concept is security, fault monitoring and costs management. In many instances a door could be jammed (blocked) and this has to be managed manually. The Azure DataLake linked with PowerBI allows general services to be managed as well as responses deployed. Lighting systems upgraded to support internal GPS (Phillips VLC) can detect authorisation levels or users in defined spaces.

Azure Streaming Services will be used to detect anomalies in streaming or *hot* data. Using thousands of IoT devices this can take advantage of micro conditions within the hospital itself. This ranges from having the right tools at hand to allowing stock management to be understood.

7. COST ANALYSIS

The average cost when deploying a BMS is between $2.50 - $7.00 per square foot (Steve Raschke, 2016). For a 300,000 square feet hospital (120 beds) that would cost at least $750,000. This very high cost means that the ROI (return on investment) takes four or more years to recover the cost of installation. It is important to recognise that this ROI time is based on easily measurable data, for example energy savings. It does not consider savings from the added health protection to patients and staff from the proposed control of airflow. With a system such as the NHS within the United Kingdom which is funded by taxpayers it is even more crucial. It does not just save the NHS money as uninfected staff or patients have less chance of catching viruses through airborne transmission, but they remain a contributing member of society.

8. FEASIBILITY ANALYSIS

It is an unfeasible expectation for existing infrastructure to be teared down and rebuilt with a fully integrated BMS. It would not just be extremely expensive, but it would also be a strain on health services with the reduction in capacity. A way to overcome this would be to do a phased refit, also known as a retrofit. The benefit of this is from the lower risk of disruption to operations and the spread of costs over a longer period of time (Resource Data Management, 2019). Retrofitting would also allow staged deployment as well as validation supported by Azure digital twins.

9. CONCLUSION

This concept has focused on using Azure as a sort of an 'immune system' that can recognize and expel contaminated air by 'breathing'. Using Azure, imagine what more can be done if we also allow the building to 'share its experience', 'touch' or even 'speak', much like a person touches and talks to others. Let's allow the hospital building to be the best team member because if their 'walls could speak' they would have a lot to say.