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Development of a Hybrid App-based Survey Methodology for Evaluating the Real-time Indoor Environmental Quality in Buildings

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Abstract. Indoor environmental quality (IEQ) and its effect on occupant well-being and comfort is an important area of study. This paper utilized the latest mobile app technology, hybrid app, to develop user-friendly periodic questionnaires in the responses of indoor environmental quality (IEQ) survey. This hybrid app technique is cost effective and easy to use, not only to users but also to administrators. The hybrid app makes the survey work become simple, fast and semi-real-time feedback can be realized by periodic questionnaires. A case study was conducted to evaluate the feasibility of the developed hybrid app, focusing on the occupants' responses on the indoor environmental quality. More than 100 responses from The Open University of Hong Kong (OUHK) were invited to provide their feedback about their personal experience about IEQ at a newly built building. The feedbacks are collected by a mobile app based periodic questionnaire survey of personal feeling about IEQ in different time slots (the beginning, middle and end of the lecture). This Hybrid app based survey shows its huge advantage in our study to help researchers to launch a safe, efficient and high data quality survey easily. Comparing to the traditional paper based, web based and native app based survey methods, in terms of development, maintenance, cost and speed, mobile device features (camera, the GPS, the accelerometer, etc.) and device's

notification system in questionnaire survey. Furthermore, the hybrid app based survey methodology can be easily used in other survey area.

Keywords: Smart app-based survey; indoor environmental quality; periodic questionnaires; occupant satisfaction.

1. Introduction

1.1. Occupant satisfaction on indoor environmental quality

Indoor Environmental Quality (IEQ) encompasses the conditions inside a building—air quality, lighting, thermal conditions, ergonomics—and their effects on occupants or residents (occupant health, wellness, comfort and productivity) (Wargocki, Wyon et al. 2000). In general, the quality of air is assessed by measuring the various physical parameters, such as temperature, humidity, CO2, CO, TVOC, PM10 and PM 2.5, etc. In Hong Kong, the Environmental Protection Department (EPD) of the Hong Kong government implemented the Indoor Air Quality Certification Scheme in 2003 to promote public awareness of IAQ issues and IAQ management in offices and public places, and a guide was published that sets out the Scheme's procedures for participation(Department 2003). Under the IAQ Certification Scheme, a benchmark consisting of two-level objectives ('excellent' or 'good' class) is used to assess the IAQ of offices and public places. The parameters assessed under the IAQ Certification Scheme are some common physical parameters mentioned above. However, it doesn't target the association between Indoor Environmental Quality and the quality of life (QoL). The harmonization of them is hard to be achieved. While, in China, the currently in force national standard, named Standards for Indoor Air Quality (SIEQ GB/T 18883-20020) includes the personal feeling index 'no odour in indoor air' in the IEQ index (2002). We may realize that besides scientific data collected by different sensors, personal feeling of occupants is a chic and important data regarding IEQ. Therefore, in this study, individual personal experience about IEQ were investigated in our survey.

Previous studies from the views of needs theory show it is incontestable that the improvement in subjective QoL happens as a result in the social and economic aspects (Charles and Liu 1984) (Liao, Fu et al. 2005) (Gulsah Yavuz, Filiz Senkal et al. 2017). It was found that the better quality environment (measured by objective indicators of pollution) are strongly related to the higher satisfaction (Liao 2009). However, the question about such a correlation between IEQ and overall QoL is not clear (despite the impact of pollution on life satisfaction has been highlighted). This demands (objective air quality on individual QoL

periodically through the influence of air quality) requires a low-cost, user friendly and periodic survey (at specific time) method for the IEQ studies.

In order to verify these relationships, we compared different survey methods (traditional paper based, electronic based and mobile based) and applied the hybrid app based survey method for collecting the data to analyze the aforementioned relationship in the Jubilee College at the Jockey Club Campus of the Open University of Hong Kong, which was accredited with the BEAM Plus Platinum Project award by the Hong Kong Green Building Council for its green campus design in 2015.

1.2. Traditional paper based survey Vs electronic based survey

In the past, paper-based questionnaires were the popular delivery mode in survey researches. They're generally straightforward to use, have comparatively low implementation prices, and have low support and training needs (Wilcox, Gallagher et al. 2012). However, paper-based survey questionnaires tend to be long-time, hard to use periodically, with a high risk of entry-related errors, massive paper storage, low security and flexibility, and difficult to distribute across geographically distributed users (Zhang, Wu et al. 2012).

With the rapid development of information and communication technologies (ICT), the survey questionnaires are able to be delivered electronically nowadays. Electronic modes of delivery can maximize the speed and scalability of data collection, and scale back its prices, with high data quality (thus addressing a number of the constraints of the paper-based instruments) (Shah, Rajgor et al. 2010). In addition, the reduction of administrative burden has been reported by (Cook, Ludens et al. 2013).

Electronic modes also likely to be more secure and flexible than traditional paper-based methods. In addition, it can support the implementation of complex skip patterns as well as the continuous periodical collection of data without temporal or geographical constraints (Coons, Gwaltney et al. 2009). Consequently, using the electronic survey questionnaires has become common in many analysis areas, e.g. study smoking behavior, tobacco use, likepain and asthma (Kastaun, Brown et al. 2017).

1.3. Mobile app based survey

A mobile app is a powerful tool for every people. With the fast development of mobile devices and ‘app’ (applications for mobile devices) technology, more and more people switch from the PC to mobile devices to follow the news, check weather and chat with friends, because mobile device App is not only support for text, but also support voice, pictures and even multimedia messaging. The

continued rise in mobile devices adoption attracted many researchers paid attention on using mobile device technology to do the questionnaire survey.

For the environment related issue we focused on in this project, mobile app is regarded, as it can get instant feedback and deal with the huge data in an effective and efficient way. In the meanwhile, the prompt analysis results may contribute to control and building management further in an easier and faster way.

Nowadays, there are three popular mobile development techniques that can be used for the questionnaire survey study: native app, web app, and hybrid app. Each technique has its own advantages and disadvantages. A native app is an application program that has been developed for a particular platform or device, such as Android or IOS (Rouse 2013). A web app is generalized for multiple platforms. It is available over the Internet through a browser and installation it on local devices is avoided. While, a hybrid app is one that combines elements of both native and web applications (Minh, Prashant et al. 2017).

Native App is an app developed essentially for one particular mobile device and is installed directly onto the device itself. Users of native apps usually download them via app stores online or the app marketplace, such as Apple App Store, Google Play store and so on. An example of a native app is the Camera+ app for Apple's iOS devices. (Rouse 2013)

Web App, on the other hand, is basically Internet-enabled apps that are accessible via the mobile device's Web browser. They need not be downloaded onto the user's mobile device in order to be accessed. The Safari browser is a good example of a mobile Web app. While, a hybrid app is one that combines elements of both native and web applications (Minh, Prashant et al. 2017).

Many studies were launched to compare them in different aspects. Some preliminary results of the comparison about completion time, response length and user experience on PC and/or mobile browsers were reported (Buskirk and Andrus 2014). In addition, in terms of design of system structure layout of user interface and types of question/response, the comparison of questionnaire items & layout design on a mobile device is reported by (Peytchev and Hill 2010). Development skills & distribution are compared in (Stangarone 2016). (Wang 2016) (Panhale 2016) investigate the development speed aspects of the native app and mobile web, and (2012) (Martin 2014) focus on the development & maintenance cost during the native app & mobile web development & deployment. Graphical/ App performance issues are also discussed in (Mel 2012). It shows that native app and hybrid app development methodologies provide a more 'professional' and good performance for end users (Sirvent Mazarico,

Campillo Carrera et al. 2015), which also presents that native app and hybrid app methods take more advantage of all the device features than web based method.

The comparisons of three types of mobile techniques including relevant limitations were summarized in Table 1. In all, hybrid app shows its significant advantages in development, maintenance cost, speed, mobile device features (camera, the GPS, the accelerometer, etc.) and device's notification system, which are quite important in survey area.

Table 1: Comparison of native app, hybrid app and mobile web

Classification	**Native**	**Hybrid**	**Web**
Skills needed to reach Android and iOS	Objective-C, iOS SDK, Java, Android SDK	HTML, CSS, Javascript, Mobile Development Framework	HTML, CSS, Javascript
Distribution	App Store/Market	App Store/Market	Web
Development speed	Slow	Moderate	Fast
Development cost	High	Moderate	Low
Maintenance cost	High	Moderate	Low
Graphical/ App performance	High	Moderate	Moderate
Camera	Yes	Yes	Yes
Push Notifications	Yes	Yes	No
Contacts	Yes	Yes	No
Offline access	Yes	Yes	Yes
Geolocation	Yes	Yes	Yes
File upload	Yes	Yes	Yes
Gyroscope	Yes	Yes	Yes
Accelerometer	Yes	Yes	Yes
Microphone	Yes	Yes	Yes

In the survey area, as there are many open source online survey software, considering the easy development & small amount of cost, many researchers used mobile web method (Petrovčič, Petrič et al. 2016) (Maloshonok and Terentev

2016) (Vieira, Oliveira et al. 2016) (Balachandran, Lee et al. 2014) (Woo, Kim et al. 2015) (Calengor 2007) for collecting the survey data, however, no 'push notifications' is fatal problem for the web-based method in the survey area, because many surveys require participants to take periodical questionnaires in desired time periods, and most surveys don't require powerful graphics (like a game). In addition, some studies used the native app (Nathalie Sonck 2013) (Glass 2015) (Kim, Yeon et al. 2015) (Susilo, Abenoza et al. 2017) (Sonck 2013) (O'Reilly-Shah, Wolf et al. 2017) (Reilly-Shah 2017) to collect relevant information (e.g. GPS, Contract info.) in their research for periodic survey.

1.4. Hybrid app based survey in the field of indoor environmental quality

For the scientists who are engaged in environmental study, it is hard for them to manage the IT techniques about survey generation and data analysis. Therefore, how to provide a user-friendly interface and simplify the operation and maintenance procedures is quite important. For the app design, the hybrid app technique was selected to achieve the goal, because it takes advantage of both native app and mobile, such as the across platform function, can handle most requirement, at a fraction of the price), and reduce the limitation in an acceptable level (as a moderate option).

We investigate the methods and modules for developing the hybrid app in the IEQ survey study in section 2 to how to create the online survey for IEQ step by step. The survey results analyzed from our hybrid app based survey are compared in section 3. Some limitation & further works are summarized (or discussed) in section 5.

2. Methodology and Implementation

2.1. Design of questionnaires

The periodic survey questionnaire in this pilot study was designed drafted by Department of Building Services Engineering (BSE), PolyU and reviewed for content and programming issues by a member of the BSE research staff. As it is periodic questionnaire, we expect the occupants' responses on questions of the indoor air environment 3 times (morning, afternoon and night) each day. Quick responses are necessary. Therefore, there are only eight questions with some basic occupant demographics information included in the questionnaire. The sample questionnaire is shown in Appendix 1. The questionnaire is 5-point scale with endpoints "1 = very dissatisfied" and "5 = very satisfied".

To integrate the questionnaires into hybrid app, three main steps were used to build the hybrid app based survey (Fig.1): 1) Create an online survey website; 2)

Wrap the online survey into hybrid app; and 3) Deploy the mobile app to different app stores (e.g. Google play and Apple store). This paper mainly describes the first 2 technical steps in section 2.2 and 2.3.

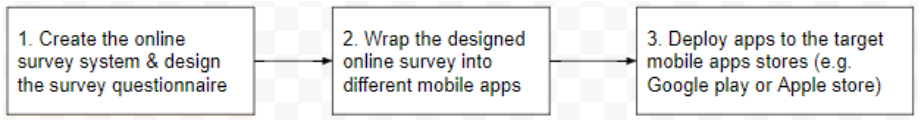


Fig. 1 Flow chart of building a hybrid app

2.2. Online survey website creation

Firstly, an online survey website is created (The free and open source on-line survey system: LimeSurvey is selected in this study). The system enables users using a web interface to develop and publish on-line surveys, collect responses, create statistics, and export the resulting data to other applications.

Here the word- 'users' is a joined name for somebody involved in the online web based survey. Actually, there are serval parties may be served as users, such as administrator, survey designer, participant and researcher. In general, the site is installed by administrator; survey questions are answered by designed groups and the data is collected by researches (Fig.2.2). The role of different 'users' is summarized in table 2.1 for clarity.

Consideration during the design. (Because the role of different parties may have different needs). For participants, they need to have a clear interface and can answer the questions in short time. For administrator, the flexibility is quite important, because there may be many different surveys running in the system for different research projects at the same time. The administrator can edit/update surveys and control the visit access when needed. For researchers, they want to collect the participants' response and other information (ip address, GPS info. and elapsed time, etc.) in an easy and efficient way.

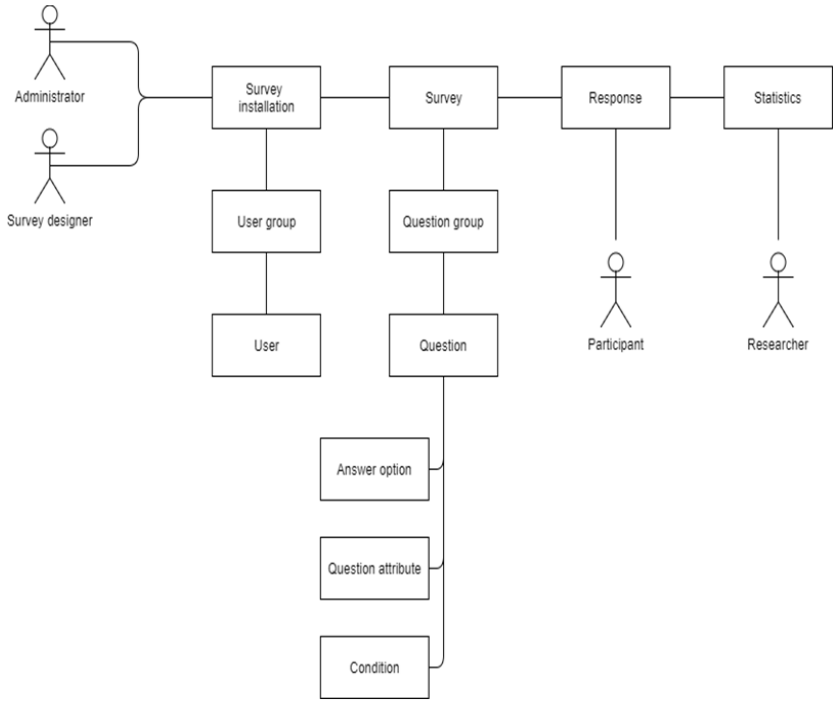


Fig.2 Roles and information flow in the survey system

Table 2. Roles in the survey system

Role Name	Role Description
Administrator	The person who created the survey site. This person manages all surveys on this site, and has full control over managing users.
Survey designer	The person who create/update/main the specific survey (assigned by administrator). In the surveys, designer get most of the same permissions as the administrator, with a few restrictions.
Participant	The survey participant
Researcher	The person who collect/export the survey result from the online system

Considering researchers will set up several surveys and wrap the different hybrid app for each research projects, researchers are able to set up different surveys in one survey system. In the survey system, its hierarchy has 3 layers: survey questions are organized into question groups (each question must be a member of a group (and only that group), in the other words, a question group is a 'page' of questions presented to the survey respondent. As shown in Fig. 2.3, it is at least one group in each survey, and a group can have questions about a similar

subject or simply be set up as a manageable number of questions. This hierarchy take an advantage on the survey design and participants responses. For example, the survey system we created are hosting 20 different surveys, researchers can easily copy/export the questions/question groups from the existing survey into a new survey, which saves a lot of efforts & resources.

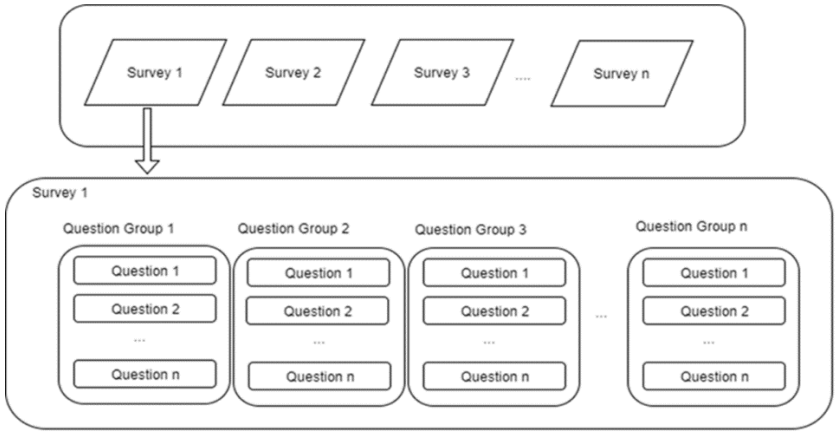


Fig. 3 The hierarchy among the survey system, question groups and questions

2.3. Wrapping the online survey into hybrid app

A hybrid app is a native, downloadable app. As shown below, it runs all or some of its user interface in an embedded browser component, which is downloaded from the app store or marketplace, stored on the device and launched like any other app. e.g. WeChat, Facebook, WhatsApp, etc.

Combining the best features of mobile and web-based app, the hybrid app provides a powerful design pattern. A "hybrid app" is an application which has been partitioned so that part runs on the mobile device and part is delivered by a server. Keeping the mobile app small reduces the cost/risk for updates, and placing most content in the web-based app allows instant updates, can be achieved by simply modification of the web server content. For example, as mentioned in the Fig. 2.3, the surveys in the survey system are independent, if researchers want to modify some questions in the survey 1, they just login the survey system to update the question contents, participants will see the latest questionnaire, no need for participants to download/upgrade the existing app.

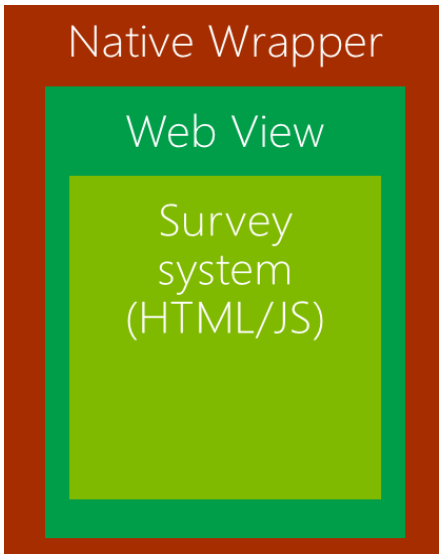
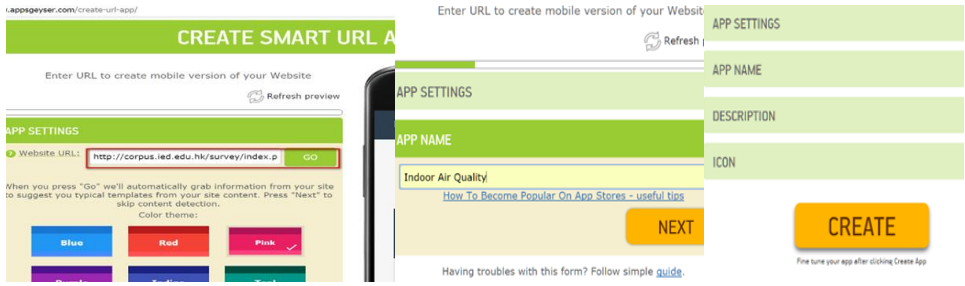


Fig. 4 The simple system structure of the hybrid app development

As there are many open-source mobile frameworks/websites that presently supports both Android and iOS platforms, we are looking for the tools which enable authoring of native mobile applications using well-known HTML, CSS, and JavaScript languages, and provide accesses to native hardware features of the mobile device through a common platform-independent JavaScript API (camera, GPS, etc.). To package the survey service, the url (generated in Limsurvey in previous section) is wrapped into app by the online service of appgeyser.com (android) and appyourself.com (ISO).

Figure 5 show three main steps from starting compile the website to install corresponding app. Here, a mobile phone running android 5.0 system was used for demonstration. Firstly, register an account from their website, and select ‘create app from a URL’ (Fig. 5a), then Create name of the survey (Fig. 5b); and generate the App (Fig. 5c); lastly for publishing in Google play.



(a) (b) (c)

Fig. 5 Steps of creating an app starting from a ready-made 'Website URL'

The features of this method are not only limited to simple to use, but also to modify the content of the questionnaires very easily. More important and useful data can also be collected from responses, such as time spent on the survey, language used, IP address of each participant, etc. The demonstration table is shown in Fig. 6.

A	B	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
IP address	Gender	Age	Date last action	Date submitted	Q1. Which	Q1. Which	Q1. Which	Q1. Which	Q2. How mar	Q3. Which	Q3. Which	Q3. Which	Q3. Which	Q3. Which	Q3. Which of th
1.34.78.45	Male	18	2018-03-07 11:17:06	2018-03-07 11:17:06	Yes	No	No	No	50 ≤ n	Yes	No	No	No	No	No
1.34.78.45	Male	18	2018-03-11 18:37:59	2018-03-11 18:37:59	Yes	No	No	No	50 ≤ n	Yes	No	No	No	No	No
1.64.17.114	Female	24	2018-03-07 11:14:06	2018-03-07 11:14:06	Yes	No	No	No	n < 10	No	No	No	No	No	Yes
1.64.17.114	Female	24	2018-03-07 17:47:56	2018-03-07 17:47:56	Yes	No	No	No	n < 10	No	No	No	No	No	Yes
103.83.247.208	Male	18	2018-03-12 13:47:03	2018-03-12 13:47:03	No	Yes	Yes	No	30 ≤ n < 50	No	No	No	No	No	No
113.254.211.164	Female	24	2018-03-07 12:32:37	2018-03-07 12:32:37	No	Yes	Yes	No	n < 10	No	No	No	No	No	No
113.254.211.164	Female	24	2018-03-10 17:11:30	2018-03-10 17:11:30	No	Yes	Yes	No	n < 10	No	No	No	No	No	No
119.236.176.155	Female	21	2018-03-10 21:42:45	2018-03-10 21:42:45	No	Yes	Yes	No	20 ≤ n < 30	No	Yes	Yes	No	No	No
119.236.176.155	Female	21	2018-03-13 13:40:12	2018-03-13 13:40:12	No	Yes	Yes	No	20 ≤ n < 30	No	Yes	Yes	No	No	No
126.54.194.28	Male	21	2018-03-10 14:06:48	2018-03-10 14:06:48	No	Yes	Yes	No	50 ≤ n	No	No	No	No	No	No
128.232.232.80	Male	24	2018-03-10 02:11:48	2018-03-10 02:11:48	Yes	No	No	No	50 ≤ n	No	No	No	No	No	No
129.180.54.138	Male	21	2018-03-09 09:33:39	2018-03-09 09:33:39	No	Yes	Yes	No	30 ≤ n < 50	No	No	Yes	No	No	No
14.0.170.195	Female	20	2018-03-06 07:33:41	2018-03-06 07:33:41	No	Yes	Yes	No	50 ≤ n	No	No	No	No	No	No
14.0.170.195	Female	20	2018-03-07 15:19:48	2018-03-07 15:19:48	No	Yes	Yes	No	50 ≤ n	No	No	No	No	No	No
14.0.236.17	Male	21	2018-03-13 11:28:31	2018-03-13 11:28:31	Yes	No	No	No	30 ≤ n < 50	Yes	Yes	No	No	No	No
14.0.236.17	Male	21	2018-03-13 18:05:34	2018-03-13 18:05:34	Yes	No	No	No	30 ≤ n < 50	Yes	Yes	No	No	No	No
140.224.193.189	Female	21	2018-03-11 14:23:40	2018-03-11 14:23:40	No	Yes	Yes	No	50 ≤ n	No	No	No	No	No	No
142.31.232.68	Male	24	2018-03-06 19:07:36	2018-03-06 19:07:36	No	Yes	Yes	No	50 ≤ n	Yes	No	Yes	No	No	No
152.142.233.127	Female	22	2018-03-09 01:16:36	2018-03-09 01:16:36	No	Yes	Yes	No	30 ≤ n < 50	No	No	Yes	No	No	Yes
152.142.233.127	Female	20	2018-03-08 23:48:04	2018-03-08 23:48:04	No	Yes	No	No	10 ≤ n < 20	No	Yes	No	No	No	No
158.132.174.151	Female	20	2018-03-10 16:01:21	2018-03-10 16:01:21	No	Yes	No	No	10 ≤ n < 20	No	Yes	No	No	No	No
158.132.174.151	Female	20	2018-03-13 10:49:57	2018-03-13 10:49:57	No	Yes	No	No	10 ≤ n < 20	No	Yes	No	No	No	No
158.132.174.190	Female	20	2018-03-10 14:07:25	2018-03-10 14:07:25	No	Yes	Yes	No	50 ≤ n	No	No	No	No	No	No

Fig. 6 Raw data of participants' responses

3. Results and Discussion

The case study was conducted to verify the feasibility of the developed hybrid app for the evaluation of the indoor environmental quality in the lecture room of the new building. The survey is taken from 07/03/2018 to 10/03/2018, in the Jubilee College at the Jockey Club Campus of the Open University of Hong Kong.

Double-glass curtain-walls are installed on the other three sides, helping to improve air quality and reduce heat and noise. In addition to this, the 'U-shaped' design and the additional opening at the lower three levels of the building can facilitate air movement and visual permeability at the street level. (Kong 2015).

Students show their high interests on using our app, as shown below, our app offers a better overlay than any traditional paper based or pc based survey, to make the questionnaire easier for the students to read. The design capabilities of our hybrid app based survey are more flexible than paper based survey, as there are some design limitations in the paper based survey. As we know that both survey methodologies are able to support single-response questions, multiple choice questions (MCQs), list questions and grid questions. Moreover, our hybrid app based survey supports more user-friendly features, e.g. drop-down options, interactive slider, star-rating options and even integrate some multimedia files.

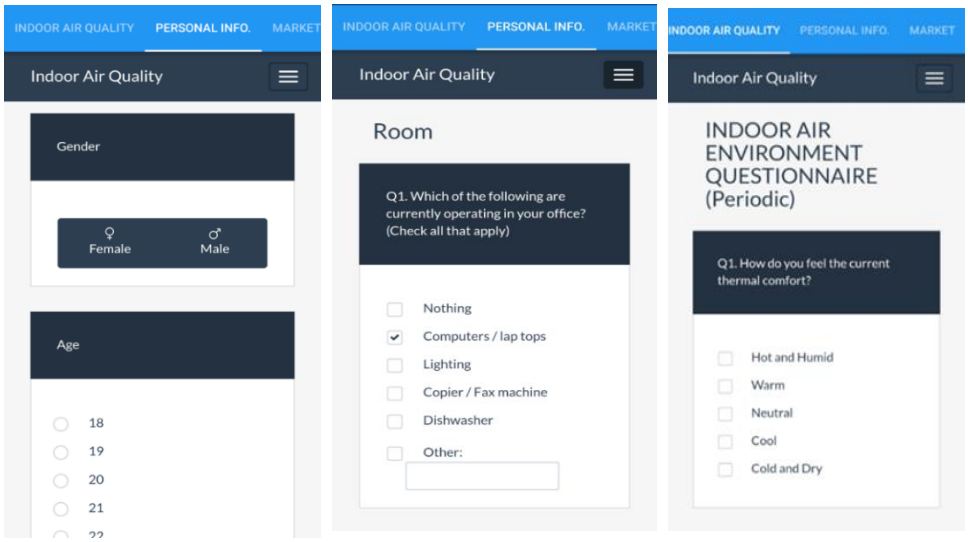


Fig. 7 Examples of interfaces of our app shown on smartphone

Also, the triggered "Push notification" function is integrated in the apps to remind students to response the periodic questionnaire, during different time slots.

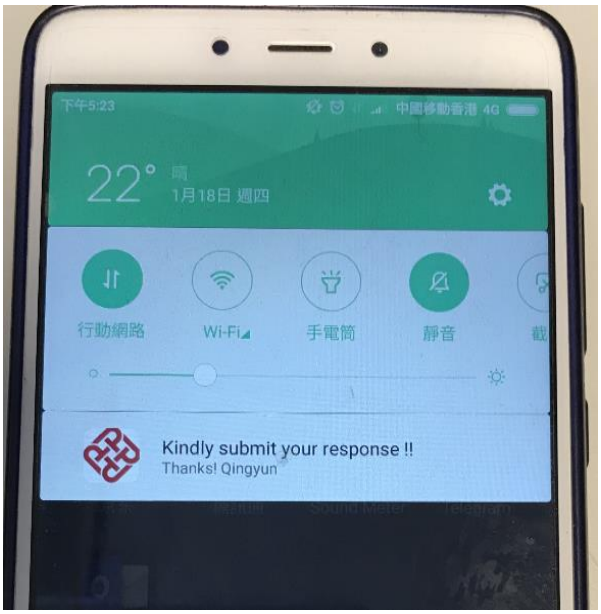


Fig. 8 Integrated "Push notification" function in the apps

In this study, the average time for students to complete the questionnaires is around 4 mins. After that, researchers can immediately to collect questionnaire survey results. As we know that the paper based survey needs plenty of time to prepare, print and collection of survey from respondents, especially, for the data collection and consolidation, as data collected should be record into excel file for further process.

The detailed results of the questionnaire survey for the indoor environmental quality can be explained in three aspects: (i) satisfaction with temperature; (ii) satisfaction with humidity; and (iii) satisfaction with air quality.

(i) Satisfaction with temperature: Nobody feel very dissatisfied on the room temperature and it reveals that 82.2% students feel ok or satisfied with the room temperature. Moreover, among the 30 dissatisfied responses, most concerns are on the temperature of the air-conditioner, as shown in Fig.9

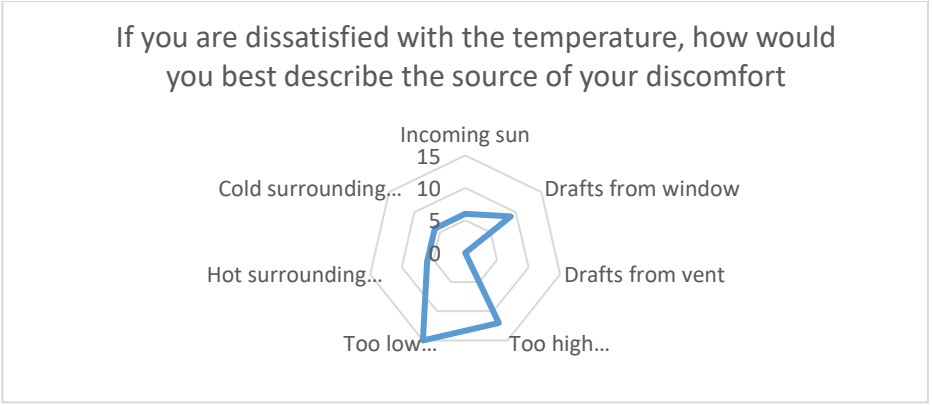


Fig. 9 Source of discomfort on temperature

(ii) Satisfaction with humidity: The satisfied and dissatisfied responses symmetric temperature and 82.2% students feel acceptable? or satisfied on the room temperature. Among the dissatisfied responses, most students were concerned about the low humidity from the outside, as shown in Fig.10.

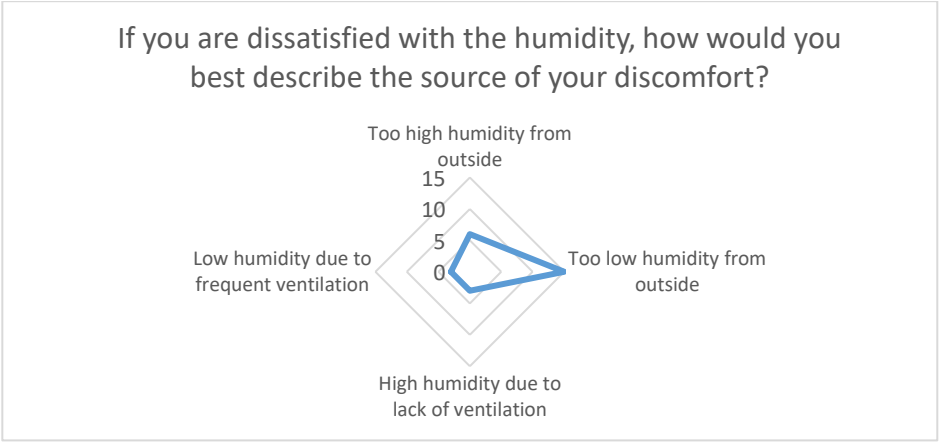


Fig. 10 Source of dissatisfaction with humidity

(iii) Satisfaction with air quality (including CO2, TVOC, micro dust): It reveals that only 22.2% students feel very dissatisfied or dissatisfied on the room air quality.

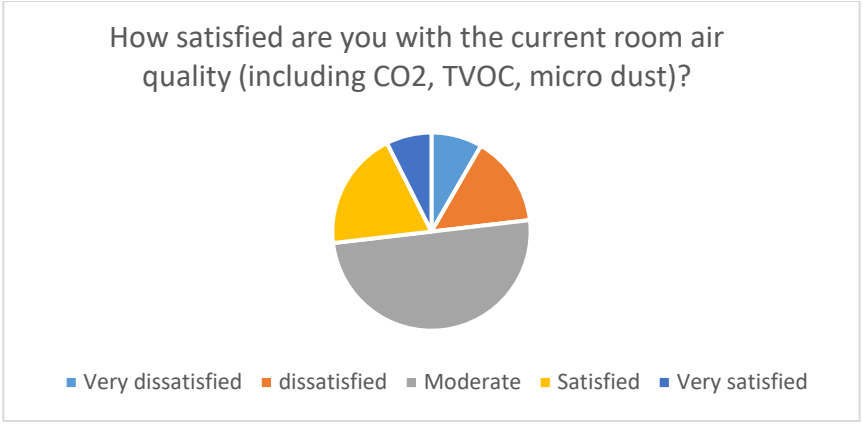


Fig. 11 Distribution on room air quality

Also, we studied in if there is any interaction between the independent variables (age and gender) with the variables (How important the following indoor environments are: 1) Temperature, 2) Humidity, 3) CO2 (Carbon dioxide), 4) TVOC (Total volatile organic compound), 5) Micro Dust (PM10, PM2.5)). However, by using the ANOVA analysis of between-subjects effects in SPSS, we find there no statistical significance with the variables and the aspects mentioned above (please see the Appendix 2 for the SPSS analysis result).

4. Conclusions

This study compared the different survey methodologies (paper based, web based, native mobile app based and hybrid mobile app based) in different aspects (development, maintenance cost, speed, mobile device features (camera, the GPS, the accelerometer, etc.) and device's notification system, etc.), and propose to use hybrid mobile app based survey in the IEQ satisfaction questionnaire survey, which helps researchers collect the periodic data more precisely than other survey methodologies. The Indoor Environment Evaluation are collected for analyzing the occupants' quality of life, and the survey data of occupants will be provided to the building manager as a reference to regulate the building's IEQ performance, and may contribute to a better IEQ management to improve occupants or residents' occupant health, wellness, comfort and productivity.

Furthermore, the students' feedback and survey data analysis, has approved our hybrid mobile app integrated survey methodology as an easier, lower cost, stable, accurate, efficient and cross platform solution in survey research, which can be easily used in other research survey area.

ACKNOWLEDGMENT:

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Appendices

Appendix 1. The periodic questionnaire used in the survey

INDOOR AIR ENVIRONMENT QUESTIONNAIRE

Gender	(Male or Female)
Age	

BASIC INFORMATION

■ **ROOM ENVIRONMENT**

Q1. Which of the following are currently operating in your office? (Check all that apply)

- ☐ Nothing
- ☐ Computers / lap tops
- ☑ Lighting
- ☐ HVAC system
- ☐ Other. Please describe :

Q2. How many people are there in the room?

- ☐ $n < 10$
- ☑ $10 \leq n < 20$
- ☐ $20 \leq n < 30$
- ☐ $n \geq 30$

■ **OCCUPANT STATUS**

Q3. Which of the following apply to your health condition? (Check all that apply)

- ☐ Athma
- ☐ Chromic cough
- ☑ Nasal congestion
- ☐ Rhinitis
- ☐ Atopy
- ☐ Eye disease
- ☐ Headache

Q4. Which of the following are your present clothing?

	Jacket	Shirt	Trousers	Skirt
Not wearing	☑	☐	☐	☐
Light	☐	☑	☐	☐
Heavy	☐	☐	☐	☐
Short	☐	☐	☑	☑
Long	☐	☐	☐	☐

Q5. Choose one of the following for your activity level.

- ☐ Reclining
- ☐ Seated
- ☐ Standing relaxed
- ☐ Light activity, standing
- ☑ Medium activity, standing
- ☐ High activity

Q6. How long have you been in the room?

- ☐ $h < 30$ minutes
- ☑ 30 minutes $\leq h < 1$ hour
- ☐ 1 hours $\leq h < 2$ hours
- ☐ 2 hours $\leq h < 3$ hours

INDOOR ENVIRONMENT EVALUATION

Q7. How do you feel the current thermal comfort (including temperature and humidity)?

- ☐ Hot and Humid
- ☐ Warm
- ☑ Neutral
- ☐ Cool
- ☐ Cold and Dry

Q8. How satisfied are you with the current room temperature?

Very dissatisfied	○	○	○	◉	○	Very satisfied

Q9. If you are dissatisfied with the temperature, how would you best describe the source of your discomfort?

- ☐ Incoming sun
- ☐ Drafts from window
- ☐ Drafts from vent
- ☐ Too high temperature of air-conditioner
- ☑ Too low temperature or air-conditioner
- ☐ Hot surrounding surfaces (floor, ceiling, wall or windows)
- ☐ Cold surrounding surfaces (floor, ceiling, wall or windows)
- ☐ Other. Please describe:

Q10. How would like to change the current room temperature?

- ☐ Cooler
- ☑ Warmer
- ☐ No change

Q11. How satisfied are you with the current room humidity?

Very dissatisfied	○	◉	○	○	○	Very satisfied

Q12. If you are dissatisfied with the humidity, how would you best describe the source of your discomfort?

- ☐ Too high humidity from outside
- ☑ Too low humidity from outside
- ☐ High humidity due to lack of ventilation
- ☐ Low humidity due to frequent ventilation
- ☐ Other. Please describe:

Q13. How satisfied are you with the current room air quality (including CO_2, TVOC, micro dust)?

Very dissatisfied	○	○	○	◉	○	Very satisfied

Q14. Which of the following changes have made in your body since you entered the room? (Check all that apply)
And if you feel any symptoms, check the intensity

- ☐ Nothing

		Symtom intensity					
☐ Drawsy	Weak	○	○	◉	○	○	Severe
☐ Shoulder stiffness	Weak	○	○	○	◉	○	Severe
☐ Headache	Weak	○	○	◉	○	○	Severe
☐ Dizziness	Weak	○	○	○	○	○	Severe
☐ Difficulty in breathing	Weak	○	○	○	○	○	Severe
☐ Sneezing	Weak	○	○	○	○	○	Severe
☐ Nasal congestion	Weak	○	○	○	○	○	Severe
☐ Allergic conjunctivitis	Weak	○	○	○	○	○	Severe
☐ Skin trouble (e.g., itching)	Weak	○	○	○	○	○	Severe

- ☐ Other. Please describe:

Q15. How satisfied are you with your current overall room environmental quality?

Very dissatisfied	○	○	○	◉	○	Very satisfied

Q16. Please check how important the following indoor environments are.
1 (Not important), 2 (Neutral), 3 (Important), 4 (Very important)

	1	*2*	*3*	*4*
Temperature	○	○	○	◉
Humidity	○	○	○	◉
CO_2 (Carbon dioxide)	○	○	○	◉
TVOC (Total volatile organic compound)	○	◉	○	○
Micro Dust (PM10, PM2.5)	○	◉	○	○

Appendix 2. The anova analysis results between the independent variables (age and gender) and the variables (How important the following indoor environments are: 1) Temperature, 2) Humidity, 3) CO2 (Carbon dioxide), 4) TVOC (Total volatile organic compound), 5) Micro Dust (PM10, PM2.5)).

Tests of Between-Subjects Effects

Dependent Variable: Q16. Please check how important the indoor environment - [Temperature] is:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	41.608[a]	9	4.623	6.337	.000	.375
Intercept	274.982	1	274.982	376.924	.000	.799
Gender	.589	1	.589	.808	.371	.008
Age	35.095	5	7.019	9.621	.000	.336
Gender * Age	2.742	3	.914	1.253	.295	.038
Error	69.307	95	.730			
Total	1038.000	105				
Corrected Total	110.914	104				

a. R Squared = .375 (Adjusted R Squared = .316)

Tests of Between-Subjects Effects

Dependent Variable: Q16. Please check how important the indoor environment - [Humidity] is:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	14.861[a]	9	1.651	2.375	.018	.184
Intercept	273.951	1	273.951	394.008	.000	.806
Gender	.116	1	.116	.167	.684	.002
Age	11.981	5	2.396	3.446	.007	.154
Gender * Age	.137	3	.046	.066	.978	.002
Error	66.053	95	.695			
Total	921.000	105				
Corrected Total	80.914	104				

a. R Squared = .184 (Adjusted R Squared = .106)

Tests of Between-Subjects Effects

Dependent Variable: Q16. Please check how important the indoor environment - [CO2 (Carbon dioxide)] is:

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	12.216[a]	9	1.357	1.530	.149	.127
Intercept	270.964	1	270.964	305.362	.000	.763
Gender	.628	1	.628	.707	.402	.007
Age	8.599	5	1.720	1.938	.095	.093
Gender * Age	.550	3	.183	.207	.892	.006
Error	84.299	95	.887			
Total	903.000	105				
Corrected Total	96.514	104				

a. R Squared = .127 (Adjusted R Squared = .044)

Tests of Between-Subjects Effects

Dependent Variable: Q16. Please check how important the indoor environment - [TVOC (Total volatile organic compound)] is

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	24.747[a]	9	2.750	3.871	.000	.268
Intercept	353.886	1	353.886	498.199	.000	.840
Gender	.308	1	.308	.433	.512	.005
Age	23.427	5	4.685	6.596	.000	.258
Gender * Age	1.574	3	.525	.739	.531	.023
Error	67.481	95	.710			
Total	1092.000	105				
Corrected Total	92.229	104				

a. R Squared = .268 (Adjusted R Squared = .199)

Tests of Between-Subjects Effects

Dependent Variable: Q16. Please check how important the indoor environment - [Micro Dust (PM10, PM2.5)] is

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	25.413[a]	9	2.824	3.518	.001	.250
Intercept	324.153	1	324.153	403.892	.000	.810
Gender	.054	1	.054	.068	.795	.001
Age	21.060	5	4.212	5.248	.000	.216
Gender * Age	2.683	3	.894	1.114	.347	.034
Error	76.244	95	.803			
Total	1083.000	105				
Corrected Total	101.657	104				

a. R Squared = .250 (Adjusted R Squared = .179)

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