Well-being and comfort of ageing people based on indoor environmental conditions: preliminary study on human-coach conversation

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Well-being and comfort of ageing people based on indoor environmental conditions: preliminary study on human-coach conversation

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Abstract: This paper presents a scientific methodology to define human-coach conversation for ageing people through virtual coaches by using indoor environmental quality (IEQ) measurements and Knowledge Graphs (KG). The impact of IEQ, i.e., acoustic, thermal, visual comfort and air quality, specifically for ageing people, is provided to define the use-case focused on improving the well-being and comfort of users starting from the environmental measurements. The sensor network to measure the IEQ in the living environment is composed of an air temperature and humidity sensor, acoustic sensor, CO2 sensor, lux meter, etc. A KG is developed, based on these measurements, in order to define a data-driven conversational strategy between the virtual coach and the user at home. An example of KG is presented to define how the measured parameters in the living environment can affect thehuman-coach conversation.

I. INTRODUCTION

Measurement of the well-being of ageing people in their living environment has become relevant, in particular, in this period of pandemic. Since ageing people are increasingly encouraged to stay home to avoid risky situations, the measurement of their well-being in their homes plays an important role for the healthcare system that can continue taking care of them remotely [1]. The impact of this trend is rising every year as the population is ageing and the number of older people worldwide is expected to rise from 12.5% in 2021 to 16.7% in 2030 and 20% in 2050 [2]. Moreover, an important aspect that needs to be considered is that older people prefer to live in their own homes instead of moving to nursing or care facilities. For this reason, ageing in place has become both a policy goal around the world and a government strategy for several countries. Ageing in place means the ability to live in one's own home for as long as confidently and comfortably possible. In this context, several actions have been taken by governments. For example, the European Commission promoted the Homes4Life Certification Scheme that certifies new and existing buildings to be age-friendly [3]. In fact, it is well known that the European building stock is not prepared to support well-being over the life course. Well- being is affected by socio-economic aspects, environmental settings and conditions, social exclusion, health and mental status. It is therefore a concept that embraces several aspects and has a great impact on older people's life. Considering that older people are more susceptible to the indoor environment because of their weak immune system and the large amount of time they spend indoors, the measurement of the indoor environmental quality (IEQ) is determinant for their health and well-being [4]. Poor IEQ is liable to cause sick building syndrome, the symptoms of which include headache, nausea, and respiratory problems. The IEQ acceptance of older adults was assessed by the following aspects: acoustic, thermal, visual comfort and indoor air quality (IAQ). All these aspects could be measured in the living environment to improve the well-being of older people and provide adequate services to them. For example, feedback, suggestions, or advice could be provided to the older users to optimize the indoor environmental conditions, e.g., opening a window when the IAQ is poor and/or drinking water if the air temperature is high in summer. In the last years, virtual coaching technologies are becoming more and more used in personalized user-system interaction to promote patient engagement and compliance, supporting older users in improving their well-being and quality of life. The experience between the older users and their virtual coach or avatar could increase the involvement of the users in achieving goals, promoting a healthier lifestyle and improving long-term behavioral change. In this context, this work aims to define a scientific methodology, for the e- VITA project "EU-Japan virtual coach for smart ageing" (H2020- SC1-DTH-04), to provide feedback and advice to older people to improve the IEQ in their living environment and subsequently their well-being and comfort perception using human-coach conversation techniques.

The paper is structured as follows: a description of the impact of the acoustic, thermal, visual comfort and IAQ on ageing people in Section II. Always in this section, the use case and the sensor network to measure the IEQ are described, and the definition of Knowledge Graphs (KG) is provided. In Section III the KG developed for the proposed use case is described and finally, conclusions follow in Section IV.

II. SCIENTIFIC METHODOLOGY

A scientific methodology is developed in this paper for providing feedback and advice to older users based on IEQ monitoring, Fig. 1. To begin with, an analysis of the state of the art based on IEQ aspects that influence the well-being of older population is provided. Considering that IEQ is based on acoustic, visual, thermal comfort and air quality, a specific use case is defined and the sensor network for IEQ monitoring in indoor environments is identified. Then, the heterogeneous database is implemented, and a KG is developed based on the measurement parameters to define the human-coach conversation between the virtual coach and the user.

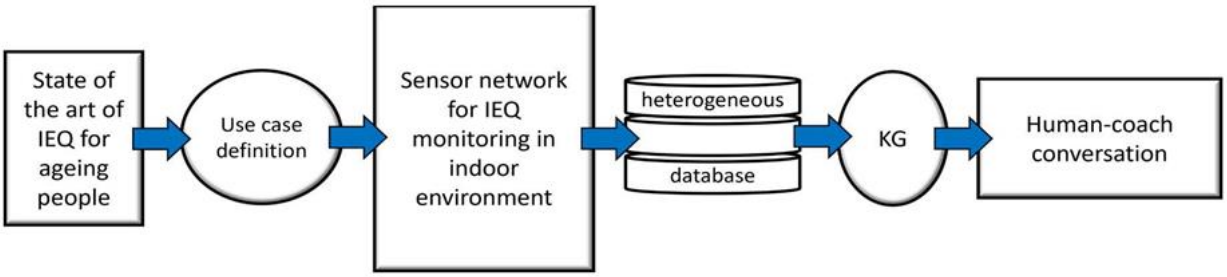

Fig. 1. Scientific methodology human-coach conversation based on IEQ monitoring.

A. Acoustic comfort

Acoustic comfort in the living environment is an increasingly important topic for improving productivity and reducing anxiety for regular users in indoor environments. Literature reports that excessive noise levels into living environments cause annoyance, sleep disturbance, irritability and also long-term health effects, such as cardiovascular disease, heart illness, hypertension and psychiatric problems [5]. Older people are more vulnerable to noise because they are more sensitive to disturbance. Consequently, providing acoustic comfort is necessary to minimize the environmental noise and support the satisfaction of the inhabitants [6]. For the World Health Organization, all undesired sounds are noise [7] and acoustic comfort in living environments is ensured by the absence of unwanted sounds, by desired sounds with the right level and quality, and by acoustic activities that do not bother other people [8]. The indoor environments could be influenced by external, e.g. transportations, machine operations, neighborhood, etc., and internal noise, e.g. conversation, home equipment, indoor activities, etc. [7].

In [9] has been reported that in living spaces like nursing homes, poor acoustic quality might have an adverse impact on the behavior and well-being of older people and their informal caregivers, decreasing their everyday quality of life. Older and younger population showed differences based on acoustic preferences. Older people prefer lower background noise, relative to younger individuals, for practical and satisfactory communication. In fact, ageing people become less sensitive to high frequencies and low voice volume. However, hearing loss was shown to affect motor capability in older adults and increase the risk of falls, indicating that the acoustic environment in living spaces is far more critical than it often seems. For this reason, it is demonstrated that acoustic interventions in indoor environments could improve the acoustic comfort for older users, e.g. acoustic curtains, wall and ceiling absorbing panels, etc.

In the living environment, the acoustic comfort limit is 55 dB(A) and the acoustic safe limit is between 55 dB(A) and 65 dB(A). It is important to consider these thresholds to guarantee the well-being of occupants [10]. In this context, limits such as noise recommend less than 30 A-weighted decibels (dB(A)) in bedrooms during the night for good quality sleep could be considered, in particular, considering that older people suffer mostly of sleep disorders. In addition to this, the recommended nighttime noise is less than 40 dB(A) of the annual average outside the bedrooms to prevent the negative health effects caused by nighttime noise. When the noise level is higher than the acoustic safe limit (55 – 65 dB(A)), the occupants could be exposed to risks such as decrease in comfort and cognitive performance for noise levels higher than 55 dB(A), stress responses (e.g., increase of electrodermal activity and cortisol) for noise levels higher than 65 dB(A) and physiological responses (e.g. heart rate variability and respiration rate) for noise levels higher than 70 dB(A).

B. Visual comfort

Visual comfort for older people in living environments takes an important role, in particular, regarding the well- being and security of the user. In fact, the proper quantity as well as the quality of illumination is of importance when designing living environments for ageing people. Quantity refers to the performance of a task (a person needs sufficient light to complete a task), while quality refers to the distribution of brightness in the space (effects such as glare, veiled reflections and visual comfort are lighting quality problems). In this context, visual comfort is defined in the European standard EN12665 [11] as the subjective condition of visual well-being induced by the visual environment. Improved visual comfort, i.e., light conditions, contributes to the improvement of quality of life, prevention of falls and improvement in ambulatory ability, especially among older persons with low vision. In this context, optimal contrast by the use of colors in the living environment where the older person spends a substantial amount of time can prevent falls [12]. In particular, some pathologies in older people, e.g. cataract and glaucoma, cause the need to use more light, better quality, but especially to increase the levels of contrast. Based on that, measurement of luminance contrast levels and visual needs considerations provide the weaknesses of an existing environment and then the possibility to proceed with its optimization [13]. In the kitchen area, over the countertop minimum 500 lux is required. In the living room is suggested to have between 300 – 1000 lux throughout the space. In particular, areas close to the floor should be carefully illuminated with 100 – 500 lux to prevent falls and accidents. For lavatory areas, approximately 200 – 500 lux is required to prevent accidents [14].

C. Thermal comfort

Thermal comfort plays a pivotal role in the well-being of the population. It is defined as the state of mind which expresses satisfaction with the thermal environment, and it is assessed using the Predicted Mean Vote (PMV) model that consists of four indoor climate parameters (ambient air temperature, relative humidity, mean radiant temperature and air speed) and two

personal factors (clothing insulation and metabolic rate) [15], [16]. Thermal comfort occurs at $-0.5 \leq PMV \leq 0.5$, while for sensitive and frail people, the suggested range is $-0.2 \leq PMV \leq 0.2$ [17]. For aging people, the health risk of exposure to rapid or extreme changes in environmental temperature presents challenges for thermal homeostasis. Thermal discomfort caused by indoor and outdoor environmental conditions (i.e. heat and cold) is a potential health risk, in particular, for older people with multiple co-morbid conditions [17]. This provides the need to tailor indoor environmental conditions to meet the thermal needs of occupants, a crucial consideration for health and well-being. For aging people with cognitive disease or stroke, providing an environment that satisfies the need of the user has a paramount role, since those users are coupled with a decrease in temperature discrimination. However, in the literature, several studies found no statistically significant age- related differences in the dependence of thermal sensation on operative temperature [18], [19]. Contrary to that, recent studies revealed that older people have low thermal sensitivity and lower thermal sensation than the PMV model used in many standards, concluding that current thermal comfort models are potentially unsuitable for predicting comfort in an older population and may significantly overprescribe comfortable temperatures. Those studies have revealed that the optimum temperature for older people to achieve thermal comfort is higher than young adults with equivalent clothing insulation, owing to lower metabolic heat production. Furthermore, females tend to be more sensitive to cold temperatures and hence prefer warmer temperatures. In [17], measures of air temperature and clothing are reported in order to mitigate potential thermal discomfort for sedentary older occupants living in residential cares. For the indoor air temperature, the values between 22.8 °C and 23.6 °C are considered a comfortable range over a year. A clothing range of 0.6 ± 0.1 has been derived from the non-dementia group. In [20], it is reported that residents of a nursing home in the Mediterranean prefer higher temperatures than caregivers and therapists. In general, field studies in buildings occupied by older people during the summer revealed that older people prefer higher temperatures than non-older adults. This preference for the higher indoor temperatures caused a higher energy consumption for heating in nursing homes in the winter period. However, the same study confirmed that, in winter, older people use clothing adjustment to adapt to the environment. In this case, the acceptability of indoor air temperature for 90% of residents ranged from 21.6 °C to 22.9 °C.

D. Indoor air quality

Urban air pollution affects the health of citizens. Several diseases are associated with air pollutions, e.g. cardiovascular morbidity, chronic obstructive pulmonary disease, pneumonia, etc. Since older people spend most of their time indoor, decreasing physical activity, they are subjected to a reduction of immunological defenses and chronic diseases which make them more at risk from the effects of air pollutants. In addition, during this pandemic period there is an increase in severe acute respiratory syndromes due to the transmission of coronavirus 2 (SARS-CoV-2, the virus that caused COVID-19). To reduce the transmission of the virus by ensuring social distancing and at the same time monitoring the physical activity carried out by the older people, in [21] the authors implemented a real-time localization system (RTLS) integrated with inertial measurement unit (IMU) sensors. Carbon monoxide (CO), carbon dioxide (CO2), formaldehyde, total volatile organic compounds (TVOC), particulate matter up to 10 micrometers size (PM10) and particle matter up to 2.5 micrometers in size (PM2.5) are the measures for the indoor air quality evaluation. In [22], it has been demonstrated a relation between high PM2.5 concentrations and respiratory diseases, blood pressure and autonomic function influence in older people both in winter and summer. Furthermore, the same study demonstrated a correlation between exposure to PM10, TVOC, CO2, bacteria and fungi and the progression of respiratory chronic disease in the same cohort. Also, in [23], it has been demonstrated the relation between the exposure to PM10 and the increase in the occurrence of acute respiratory symptoms and reduced lung functions in aging people. Another age-related problem caused by poor IAQ is poorer cognitive performance [24]. Since the measurement of CO2 can provide a good estimation of the quality of IAQ (when the CO2 level is lower than 1000 ppm in an indoor environment), coaching methods could be realized in order to apply ventilation strategies and behavioral changes [25].

E. Use case and sensors network definition

In this paragraph, a specific use case is defined for the e- VITA project. Feedback and advice to improve the well-being and comfort of older users living in their homes are provided using the measurement parameters acquired through a sensor network that could be installed in the users' homes. For the specific use case of IEQ monitoring, the heterogeneous set of sensors that could be installed in the living environment could be characterized as in Fig. 2 and described in Table 1. In particular, the measurement parameters are air temperature, relative humidity, CO2 concentration, acoustic level, and light level. Measurement of thermal comfort could be provided using a more complex sensor called Comfort Eye [26] with which the PMV is computed. The feedback and advice to the users in the e-VITA project are provided using robots, e.g.Nao, Daruma and Santo, but also using Avatars and Androids.

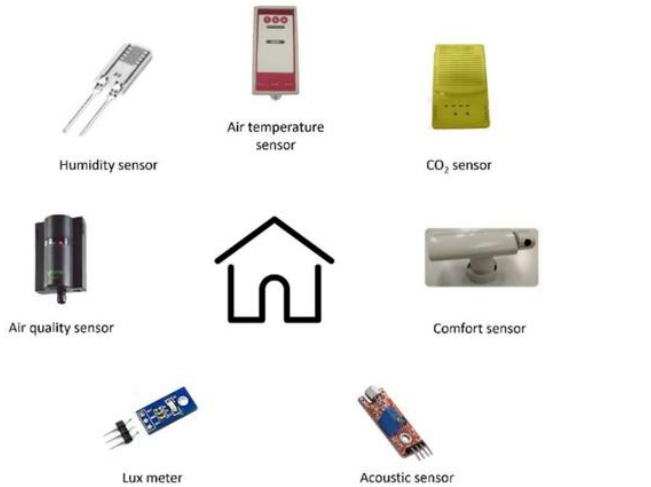

Fig. 2. Sensor network for IEQ monitoring in living environment.

Table 1. Example of sensors that could be installed in the living environmentto measure the IEQ.

Sensor	Measured parameter	Measuring range	Accuracy
Air Temperature sensor	Air temperature	0 °C to 50 °C	± 0,3 °C
Humidity sensor	Relative humidity	0 to 100 %	± 3 %
CO_2 sensor	CO_2 concentration	0 to 5000 ppm	± 50 ppm (0 to 1000 ppm) or ± 5% (1000 to 5000 ppm)
Acoustic level	Noise level	35 to 120 dB	± 0,1 dB
Comfort sensor	PMV	-3 to +3	± 0,1
Lux meter	Light level	0 to 99999 lux	± 3 %

F. Knowledge Graph

Knowledge Graphs (KG) are developed for the use case to provide feedback and advice to the user through the virtual coach. KG are networks of entities and connecting links (edges). The entities represent real-world objects, events, situations, or concepts, and the edges denote relationships between them. Relationships can be directed or undirected, and they can also have properties. KG are visualized in a graph structure and can be stored in a graph database. In this paper, the attention is focused on labelled property graphs, where properties include specific information about entities, see example in Fig. 3.

Compared with traditional relational databases, graph databases are flexible and easily extendable, and they focus on the relationships rather than on the data elements. This is a considerable advantage in present-day data problems which deal with heterogeneous data and many-to-many relationships.

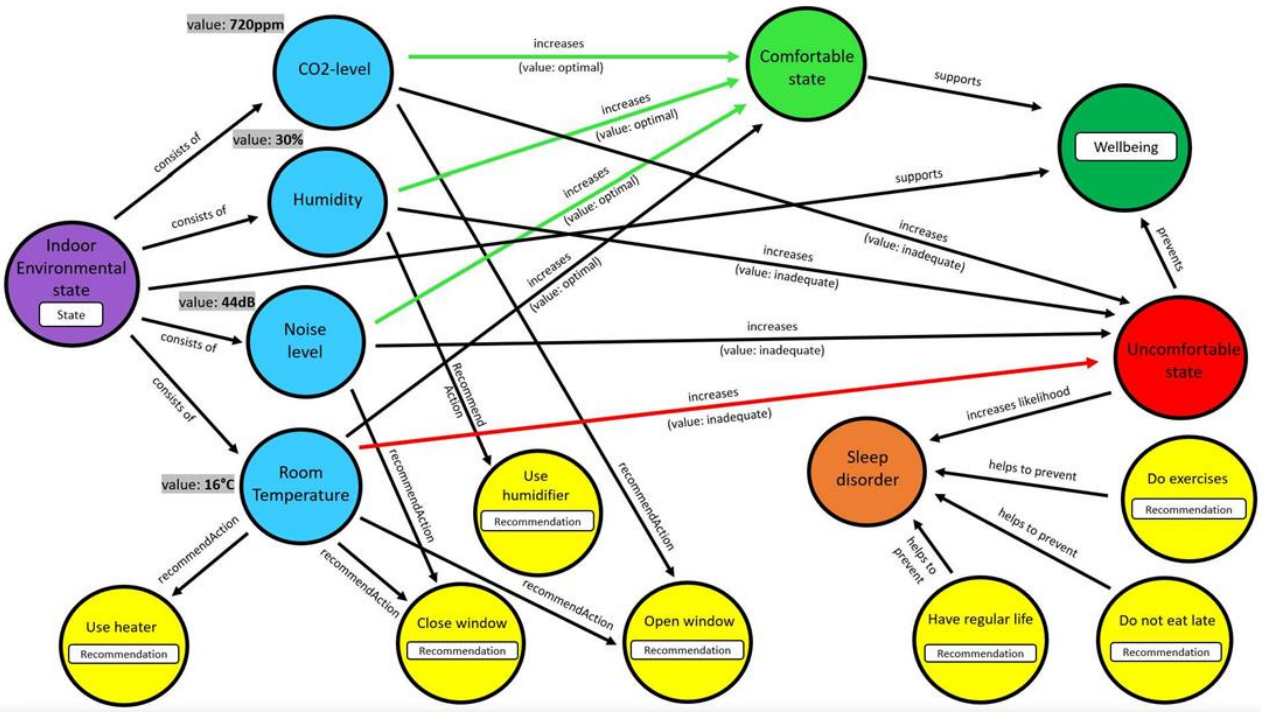

Fig. 3. Knowledge Graph based on IEQ monitoring.

III. RESULTS

For this specific use case, KG are used for storing knowledge for the coaching system and enabling the dialogue manager to talk about the relevant interesting topic. The dialogue manager recognizes the main concepts in the user's utterance, maps them onto the entities and relations that it knows about, and having recognized the user's intent, it makes knowledge base queries to find the necessary information to answer the user query.

Fig. 4 shows an example of KG in the environmental sensor domain, and the effect of environmental state on well- being. For easy readability, the nodes are color-coded in the figure. The blue nodes represent some of the different factors that can be measured to estimate the indoor environmental state, e.g., in this figure: room-temperature and CO2 concentration. The yellow nodes denote what kind of recommended actions are available given the sensor values of a particular state. Green and red nodes represent the state of comfortableness and uncomfortableness, which can increase depending on the optimal or inadequate values of the environmental factors. The main concept of indoor environmental state is colored lilac and well-being deep green.

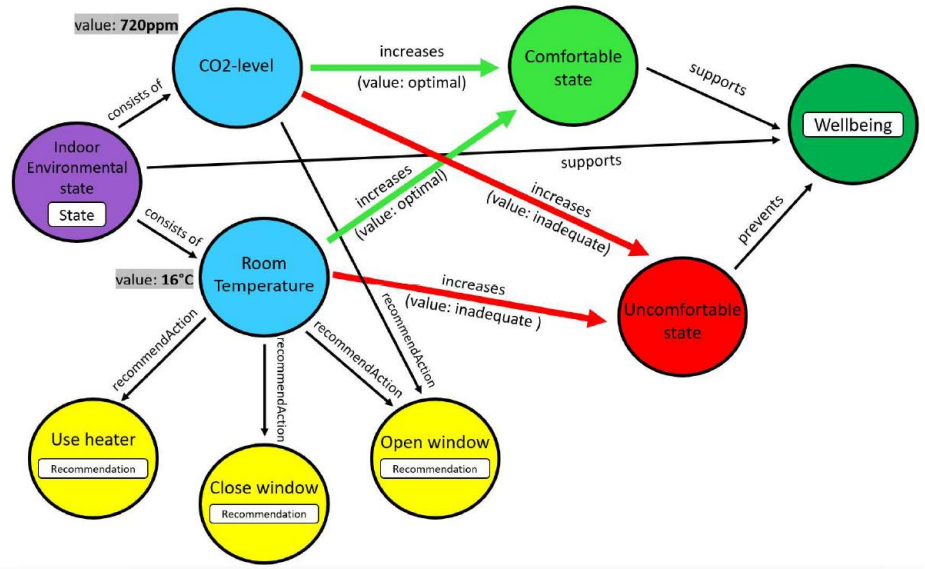

Fig. 4. Example of Knowledge Graph based on room temperature and CO2-level for IEQ monitoring.

More nodes can be easily added to the graph with appropriate links. For instance, Fig. 3 shows a graph that also includes noise level and humidity as environmental factors, while another topic, namely sleep disorder, is added to the graph by linking it to the node uncomfortable state as an example whose probability is increased by the uncomfortable state. It is thus possible to trace back the reasons for sleep disorder by following first the link increases likelihood to the uncomfortable state and then following the increases links from this state with the value inadequate, to the nodes which represent environmental factors. Consequently, we can infer that the probability of sleep disorder is increased by uncomfortable state, which is increased by the inadequate valued environmental factors like CO2 concentration, humidity, noise level and room temperature.

The graph also shows how the different environmental sensors support the user's feeling of comfortable or uncomfortable state, depending on if the value measured by the sensor is “optimal” or “inadequate”. Table 2 shows the threshold values for “optimal” and “inadequate” labels for each of the measured quantities. This is a simplification of how the sensor information is represented in the graph, but since the continuous-valued sensor information cannot be represented in the graph, we assume that there is a component that estimates the sensor state into the labeled categories, and subsequently the dialogue system will use the category label for estimating the value of the environmental state in its further processing.

Table 2. Threshold values for “optimal” and “inadequate” labels for the measured parameters.

Measured parameter	**Labels**	
	Optimal	**Inadequate**
Room temperature	20 °C – 25 °C	< 20 °C > 25 °C
Humidity	30 % – 50 %	< 30 % > 50 %
CO_2 concentration	< 1000 ppm	≥ 1000 ppm
Noise level	≤ 40 dB	> 40 dB

The sensor values in Fig. 4 are given as examples of a particular state where e.g., room temperature is 16 °C and CO2 concentration is 720 ppm. In this hypothetical situation, CO2 measurement point to the comfortable state since 720 ppm guarantees a good IAQ, while room-temperature that the system finds too low points to the uncomfortable state, and thus it can suggest the user to close the window and use the heater.

The knowledge graph supports small interactions like:

Q: “What kind of environmental factors does the environmental state consist of?”

A: “There are four different factors: room temperature, noise level, humidity, and CO2 concentration.”

Q: “I see. How can the CO2 concentration support my well-being?”

A: “If the value is optimal, less than 1000 ppm, then the air quality is good, and it increases the comfortable state which supports well-being.”

Q: “Can you tell me what I can do to prevent sleep disorders?”

A: “The following helps to prevent sleep disorders: regular lifestyle, do not eat late, and do exercises.”

Q: “What causes sleep disorder?”

A: “Uncomfortable state can increase the probability of sleep disorder. Do you want to know what uncomfortable state increases?”

Q: “Yes, tell me what increases the uncomfortable state.”

A: “Uncomfortable state is increased by inadequate levels of CO2, humidity, noise and inadequate air temperature.”

Q: “Thank you.”

A: “Thank you. Is there anything else you would like to know?”

Q: “No thanks, that is all.”

A: “Anyway, I notice that the room temperature has dropped to 16 °C. Please close the window and turn on the heater.”

Q: “Oh, thanks very much for the recommendation. I'll do this.”

A: “Thank you.”

IV. CONCLUSIONS

This paper presents a scientific methodology to provide data-driven human-coach conversation for ageing people in the living environment. The conversational strategy is based on IEQ measurements acquired at the user’s home since it is identified that the measure of acoustic, thermal, visual comfort and indoor air quality have an impact on the well-being and comfort of ageing people. The KG is used to identify the relationships between the measurements and the well-being of the user and to develop human-coach conversations based on these relationships.

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REFERENCES

[1] S. Casaccia *et al.*, «Measurement of Users’ Well-Being Through Domotic Sensors and Machine Learning Algorithms», *IEEE Sens. J.*, vol. 20, n. 14, pagg. 8029–8038, lug. 2020, doi: 10.1109/JSEN.2020.2981209.

[2] U. Nations, «World population ageing», *Dep. Econ. Soc. Aff.*, pagg. 1–164, 2015.

[3] S. Casaccia, G. M. Revel, G. Cosoli, e L. Scalise, «Assessment of Domestic Well-Being: From Perception to Measurement», *IEEE Instrum. Meas. Mag.*, vol. 24, n. 6, pagg. 58–67, set. 2021, doi: 10.1109/MIM.2021.9513641.

[4] H. Zhan, J. Yu, e R. Yu, «Assessment of older adults’ acceptance of IEQ in nursing homes using both subjective and objective methods», *Build. Environ.*, vol. 203, pag. 108063, ott. 2021, doi: 10.1016/j.buildenv.2021.108063.

[5] L. Claudi, M. Arnesano, P. Chiariotti, G. Battista, e G. M. Revel, «A soft-sensing approach for the evaluation of the acoustic comfort due to building envelope protection against external noise», *Measurement*, vol. 146, pagg. 675–688, nov. 2019, doi: 10.1016/j.measurement.2019.07.003.

[6] G. Marques e R. Pitarma, «A Real-Time Noise Monitoring System Based on Internet of Things for Enhanced Acoustic Comfort and Occupational Health», *IEEE Access*, vol. 8, pagg. 139741–139755, 2020, doi: 10.1109/ACCESS.2020.3012919.

[7] I. Mujan, A. S. Anđelković, V. Munćan, M. Kljajić, e D. Ružić, «Influence of indoor environmental quality on human health and productivity - A review», *J. Clean. Prod.*, vol. 217, pagg. 646–657, apr. 2019, doi: 10.1016/j.jclepro.2019.01.307.

[8] N. G. Vardaxis, D. Bard, e K. Persson Waye, «Review of acoustic comfort evaluation in dwellings—part I: Associations of acoustic field data to subjective responses from building surveys», *Build. Acoust.*, vol. 25, n. 2, pagg. 151–170, giu. 2018, doi: 10.1177/1351010X18762687.

[9] P. Thomas *et al.*, «Evaluation and improvement of the acoustic comfort in nursing homes: a case study in Flanders, Belgium», pag. 8. R. Golmohammadi, E. Darvishi, M. Shafiee Motlagh, J. Faradmal, M. Aliabadi, e M. A. Rodrigues, «Prediction of occupational exposure limits for noise-induced non-auditory effects», *Appl. Ergon.*, vol. 99, pag. 103641, feb. 2022, doi: 10.1016/j.apergo.2021.103641.

[10] «EN 12665:2011 - Light and lighting - Basic terms and criteria for specifying lighting requirements», *iTeh Standards Store*. https://standards.iteh.ai/catalog/standards/cen/d7c62c9a-95ac-4ed8- 9a40-862805aa5afc/en-12665-2011 (consultato 3 febbraio 2022).

[11] A. H. Abdelhafiz e C. A. Austin, «Visual factors should be assessed in older people presenting with falls or hip fracture», *Age Ageing*, vol. 32, n. 1, pagg. 26–30, gen. 2003, doi: 10.1093/ageing/32.1.26.

[12] E. Guerry, C. D. Gălățanu, L. Canale, e G. Zissis, «Luminance Contrast Assessment for Elderly Visual Comfort Using Imaging Measurements», *Procedia Manuf.*, vol. 32, pagg. 474–479, gen. 2019, doi: 10.1016/j.promfg.2019.02.242.

[13] Faculty of Architecture, Yasar University, Izmir, Turkey e A. C. Kunduraci, «LIGHTING DESIGN FOR THE AGING EYES», *MATTER Int. J. Sci. Technol.*, vol. 3, n. 3, pagg. 185–194, dic. 2017, doi: 10.20319/mijst.2017.33.185194.

[14] I. Pigliautile, S. Casaccia, N. Morresi, M. Arnesano, A. L. Pisello, e G. M. Revel, «Assessing occupants’ personal attributes in relation to human perception of environmental comfort: Measurement procedure and data analysis», *Build. Environ.*, vol. 177, pag. 106901, giu. 2020, doi: 10.1016/j.buildenv.2020.106901.

[15] N. Morresi *et al.*, «Sensing Physiological and Environmental Quantities to Measure Human Thermal Comfort Through Machine Learning Techniques», *IEEE Sens. J.*, vol. 21, n. 10, pagg. 12322– 12337, mag. 2021, doi: 10.1109/JSEN.2021.3064707.

[16] C. Y. Yi, C. Peng, C. Childs, e D. Robinson, «Thermal comfort modelling of older people living in care homes: An evaluation of heat balance, adaptive comfort, and thermographic methods», *Build. Environ.*, nov. 2021, Consultato: 3 febbraio 2022. [Online]. Disponibile su: https://eprints.whiterose.ac.uk/180089/

[17] R. Becker e M. Paciuk, «Thermal comfort in residential buildings – Failure to predict by Standard model», *Build. Environ.*, vol. 44, n. 5, pagg. 948–960, mag. 2009, doi: 10.1016/j.buildenv.2008.06.011.

[18] M. Indraganti e K. D. Rao, «Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot and dry climate with seasonal variations», *Energy Build.*, vol. 42, n. 3, pagg. 273–281, mar. 2010, doi: 10.1016/j.enbuild.2009.09.003.

[19] N. Forcada, M. Gangolells, M. Casals, B. Tejedor, M. Macarulla, e K. Gaspar, «Field study on thermal comfort in nursing homes in heated environments», *Energy Build.*, vol. 244, pag. 111032, ago. 2021, doi: 10.1016/j.enbuild.2021.111032.

[20] S. Casaccia, R. Naccarelli, S. Moccia, L. Migliorelli, E. Frontoni, e G. M. Revel, «Development of a measurement setup to detect the level of physical activity and social distancing of ageing people in a social garden during COVID-19 pandemic», *Measurement*, vol. 184, pag. 109946, nov. 2021, doi: 10.1016/j.measurement.2021.109946.

[21] A. Mendes *et al.*, «The impact of indoor air quality and contaminants on respiratory health of older people living in long-term care residences in Porto», *Age Ageing*, vol. 45, n. 1, pagg. 136–142, gen. 2016, doi: 10.1093/ageing/afv157.

[22] M. Simoni, M. S. Jaakkola, L. Carrozzi, S. Baldacci, F. D. Pede, e G. Viegi, «Indoor air pollution and respiratory health in the elderly», *Eur. Respir. J.*, vol. 21, n. 40 suppl, pagg. 15s–20s, mag. 2003, doi: 10.1183/09031936.03.00403603.

[23] J. L. Saenz, R. Wong, e J. A. Ailshire, «Indoor air pollution and cognitive function among older Mexican adults», *J Epidemiol Community Health*, vol. 72, n. 1, pagg. 21–26, gen. 2018, doi: 10.1136/jech-2017-209704.

[24] M. R. Laurent e J. Frans, «Monitors to improve indoor air carbon dioxide concentrations in the hospital: A randomized crossover trial», *Sci. Total Environ.*, vol. 806, pag. 151349, feb. 2022, doi: 10.1016/j.scitotenv.2021.151349.

[25] M. Arnesano, L. Violini, e G. Revel, «An IoT measurement solution for continuous indoor environmental quality monitoring for buildings renovation», *ACTA IMEKO*, vol. 10, pagg. 230–238, dic. 2021, doi: 10.21014/acta_imeko.v10i4.1182.