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User satisfaction evaluation of Indoor Environmental Quality for office buildings

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Avaliação da satisfação dos usuários com a Qualidade Ambiental Interna para edifícios de escritórios

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Luiza Tavares de Castro

Avaliação da satisfação dos usuários com a Qualidade Ambiental Interna para edifícios de escritórios

O presente trabalho em nível de Mestrado foi avaliado e aprovado, em 19 de outubro de 2022, pela banca examinadora composta pelos seguintes membros:

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RESUMO

Para garantir boas condições de conforto ambiental e satisfação aos seus ocupantes, a Qualidade Ambiental Interna (QAI) do ambiente construído deve ser avaliada, o que requer agregar dados que forneçam um panorama global do desempenho do edifício. As recomendações para avaliar a satisfação com a QAI apontam para o avanço dos métodos em abordagens novas e inovadoras, sugerindo que seja realizada a partir da combinação de dados quantitativos e qualitativos que forneçam informações empíricas para melhorar o ambiente interno. Esta pesquisa tem como objetivo propor uma estrutura de avaliação da satisfação do usuário com o local de trabalho em relação à Qualidade Ambiental Interna para edifícios de escritórios, concentrando-se no desenvolvimento de uma pesquisa longitudinal para identificar a percepção dos ocupantes sobre questões relacionadas à QAI para obter um diagnóstico abrangente do edifício. Nesse sentido, uma estrutura de avaliação com foco na fase de ocupação é proposta, e destina-se à criação um processo contínuo e gradual de coleta de dados para identificação de problemas, implementação de ações corretivas necessárias e acompanhamento para reavaliações. Este processo alinha-se ao modelo de *Building Performance Evaluation*, ou na sigla em inglês BPE, e não só permite uma adaptação a longo prazo, mas, principalmente, sugere a melhoria contínua da satisfação do usuário com os parâmetros da QAI avaliados. A estrutura é composta por três módulos projetados para serem executados através de uma abordagem de método misto, combinando dados quantitativos (medições físicas de parâmetros ambientais) e qualitativos (instrumentos de pesquisa com usuários), visando a triangulação de dados. Nesse contexto, esta pesquisa foca no desenvolvimento de um instrumento de pesquisa (questionário longitudinal) para coletar dados a respeito da percepção dos usuários com a QAI. A fim de reduzir a extensão do questionário e ainda assim abordar todos os tópicos relevantes, a estrutura principal do questionário foi dividida em duas partes hierárquicas: I - identificação do domínio de desconforto e II - questões de aprofundamento. O instrumento elaborado foi testado a fim de identificar pontos fracos e ajustes necessários. Os testes foram realizados com o objetivo de encontrar evidências de validação de conteúdo e aparente. Uma aplicação mais ampla foi conduzida com funcionários de escritórios em geral em um estudo piloto com 115 voluntários a fim de simular a aplicação real. A avaliação do questionário pelos participantes indicou adequação do instrumento para medir a satisfação com a QAI em seu ambiente de trabalho, que obteve uma pontuação média de 4,75 de um total de 5 pontos. Explorando os dados obtidos, foram sugeridos indicadores de desempenho, bem como possíveis resultados complementares a serem extraídos da aplicação do instrumento, que podem ajudar na compreensão das particularidades do edifício e apoiar o processo de tomada de decisão, ajudando a identificar possíveis recomendações para a QAI e o aumento da satisfação do usuário, por exemplo a estratificação dos dados por tipo de layout e tempo na estação e trabalho. A análise crítica dos resultados do estudo piloto também levantou outras revisões importantes no instrumento, como a padronização das escalas de avaliação, seção de privacidade e randomização da lista de itens das questões.

Palavras-chave: Qualidade Ambiental Interna. Satisfação dos usuários. Ambientes de escritório.

RESUMO EXPANDIDO

Introdução

Os edifícios existem para atender às necessidades humanas, e as pessoas tendem a se comportar proativamente no ambiente construído buscando condições pessoais confortáveis. O comportamento humano em ambientes internos é baseado em como as pessoas usam, percebem e reagem a esse ambiente, interagindo com o edifício. Em edifícios de escritórios, tais comportamentos podem afetar significativamente tanto o consumo de energia quanto a Qualidade do Ambiente Interno (QAI). Melhorias nos parâmetros do QAI do escritório podem trazer grandes benefícios à saúde e ao bem-estar dos funcionários, assim como benefícios para as organizações. Nesse sentido, colaborações entre gestores prediais e de pessoal podem fornecer insights sobre a satisfação dos usuários com o ambiente interno.

Estudos recentes têm buscado conjuntos de indicadores que focam nos usuários, e podem orientar a operação do edifício para satisfazer as demandas dos ocupantes. Portanto, para monitorar efetivamente a satisfação em edifícios de escritórios é necessário melhorar a definição do que e quando precisa ser rastreado e medido, e como cruzar e expressar os resultados. O conceito de uma estrutura para avaliação sistemática do desempenho do ambiente construído é definido como Avaliação de Desempenho de Edifícios (Building Performance Evaluation, na sigla em inglês BPE). Estudos de Avaliação Pós-ocupação (APO) consistem na fase cinco das seis fases do ciclo de vida do edifício previstas na estrutura do modelo (planejamento, programação, projeto, construção, ocupação e futura adaptabilidade da estrutura), e foca em como os edifícios funcionam após serem ocupados. É definida como uma abordagem geral de obtenção de feedback sobre o desempenho de um edifício em uso, incluindo desempenho energético, QAI, satisfação dos ocupantes etc.

Os níveis de satisfação ou insatisfação percebidos pelos usuários em seu espaço de trabalho é uma noção que tem guiado a avaliação do edifício, referindo-se aos processos através dos quais os usuários conhecem e julgam seu ambiente físico. As recomendações para avaliar a satisfação com a QAI apontam para o avanço dos métodos em abordagens novas e inovadoras, sugerindo que seja avaliada a partir da combinação de dados quantitativos e qualitativos que forneçam informações empíricas para melhorar o ambiente interno. A consideração importante é possibilitar que as pessoas experimentem as condições ambientais que preferem.

A partir desta visão geral, existe a lacuna para uma estrutura de avaliação que combine a tecnologia atual de monitoramento ambiental com um cenário abrangente da percepção do usuário no local de trabalho, que deve ser consistente e, ainda assim, flexível o suficiente para se adaptar à vida útil dos edifícios. Dentro deste contexto, instrumentos para avaliar a percepção do usuário podem ser aprimorados, ampliando a comunicação entre as partes envolvidas, priorizando a sua satisfação com a QAI em ambientes de escritório.

Objetivos

Esta pesquisa tem como objetivo propor uma estrutura de avaliação da satisfação do usuário com o local de trabalho em relação à Qualidade Ambiental Interna (QAI) para edifícios de escritórios, concentrando-se no desenvolvimento de uma pesquisa longitudinal para identificar a percepção dos ocupantes sobre questões relacionadas à QAI para obter um diagnóstico abrangente do edifício.

Desenvolvimento da estrutura de avaliação

Nesse sentido, uma estrutura de avaliação com foco na fase de ocupação do edifício é proposta, e destina-se à criação um processo contínuo e gradual de coleta de dados para identificação de problemas, implementação de ações corretivas necessárias e acompanhamento para reavaliações. Este processo de avaliação contínua alinha-se ao modelo de Avaliação de Performance do Edifício, ou na sigla em inglês BPE (*Building Performance Evaluation*), e não só permite uma adaptação a longo prazo para proprietários e gerentes de edifícios, mas, principalmente, sugere também uma melhoria contínua da satisfação do usuário com os parâmetros da QAI avaliados. A estrutura é composta por três módulos projetados para serem executados através de uma abordagem de método misto, combinando dados quantitativos (medições físicas de parâmetros ambientais do edifício) e qualitativos (ferramentas de pesquisa com usuários), visando a triangulação das informações obtidas.

O primeiro módulo, ou *Standard*, destina-se a explorar e retratar a situação do edifício com a QAI, compondo um diagnóstico. O início do processo de coleta de dados é o *Preset Data*, que constitui no conjunto de informações básicas sobre o edifício avaliado, obtidos tanto na fase anterior do BPE, ou seja, com equipes de projeto e execução, quanto com Gerentes de Instalações Prediais e Recursos Humanos. Uma vez que estes dados estejam disponíveis, é iniciada a coleta de dados físicos do edifício, a partir da implementação de sistemas de monitoramento contínuo da QAI, que devem fornecer dados de medições físicas das áreas ocupadas ao longo de todo o processo de avaliação. Para a coleta de dados subjetivos, a aplicação de uma pesquisa longitudinal é proposta, a fim de obter informações detalhadas sobre a satisfação dos ocupantes. Os indicadores de desempenho para o módulo *Standard* ficam restritos ao cumprimento de normas aplicáveis, considerando que este seja o desempenho mínimo e uma prioridade que todo edifício deve atingir. Caso a conformidade normativa ou índices razoáveis de satisfação não forem atingidos, este módulo deve trazer recomendações de melhorias a serem implementadas, e submetidos a reavaliação no próximo módulo. Indicadores também são usados para o benchmarking com outros edifícios de tipologia similar.

O segundo módulo, ou *Completo*, começa após a implementação dos ajustes sugeridos para melhorar o desempenho em relação ao módulo anterior. Assim, outra rodada de coleta de dados subjetivos deve ser feita, agora com foco em interações instantâneas com os ocupantes. Este módulo se destina a aprofundar a análise dos dados coletados no módulo *Standard*, ajudando a identificar os pontos fortes e fracos tanto na operação do edifício quanto na gestão de pessoas, sendo o estágio no qual diferentes profissionais e especialistas são envolvidos, contribuindo para identificar os custos e benefícios de cada ação corretiva sob perspectivas diferentes e complementares. A proposta para avaliação do módulo *Completo* consiste em selecionar os indicadores de performance adequados a partir de um conjunto predefinido de índices, de acordo com os principais objetivos operacionais. Cada indicador selecionado deve ser seguido por uma indicação de seus aspectos críticos, com recomendações que orientem as melhorias necessárias. Para o benchmarking, é possível comparar os índices selecionados não apenas com outros edifícios de tipologia similar, mas também com o próprio edifício, expressando o progresso obtido em relação aos resultados do módulo *Standard*.

O terceiro módulo, ou *Avançado*, considera que as condições desejadas tenham sido alcançadas a partir de estratégias de operação e outras melhorias sugeridas nos módulos anteriores, aprimorando o desempenho da QAI e a satisfação do usuário. Portanto, esta etapa consiste em monitorar regularmente o status do edifício, a fim de acompanhar os indicadores de acordo. Para isso, o monitoramento contínuo das medições objetivas do edifício segue as práticas operacionais e mantém contato com a percepção dos usuários, aplicando pesquisas de satisfação instantâneas com menor frequência. Este é o momento em que os resultados do benchmarking se tornam dinâmicos, permitindo a comparação dos dados do edifício com o próprio histórico obtido ao longo do tempo. O desenvolvimento do questionário que prevê a interação instantânea com os usuários, seguindo as diretrizes da estrutura de avaliação proposta para os módulos *Completo* e *Avançado* deve ser realizado em trabalhos futuros.

Desenvolvimento do questionário longitudinal

A partir do contexto apresentado, foi desenvolvido neste estudo um instrumento de pesquisa (questionário longitudinal) para coletar dados a respeito da percepção dos usuários com a QAI, projetado para ser adotado no módulo *Standard* e que, em conjunto com o monitoramento das condições físicas do ambiente, consolidam o diagnóstico do edifício previsto para o mesmo módulo. O questionário longitudinal foi elaborado a partir da análise comparativa de pesquisas de satisfação dos usuários selecionadas na revisão internacional de literatura e adotadas como referência (BUS, CBE Occupant Survey, BOSSA Time Lapse e SHE). Paralelamente, foram realizadas entrevistas exploratórias com profissionais de mercado que atuam como gerentes de Recursos Humanos a fim de compreender as práticas atuais da indústria relacionadas às pesquisas realizadas e os interesses das organizações a respeito de seus colaboradores. A partir dessas entrevistas, foi possível identificar que as denominadas “pesquisas de clima organizacional” podem funcionar como uma conexão com a estrutura de avaliação proposta, uma vez que reconhece em seu escopo que o ambiente construído exerce grande influência no engajamento dos colaboradores. Portanto, foi criada uma pergunta de transição com foco na satisfação dos usuários com a QAI (denominada Q0 nesta pesquisa) para vincular a pesquisa de clima organizacional e a pesquisa de satisfação dos ocupantes desenvolvida neste estudo, adotando-a como um gatilho para identificar índices de insatisfação. O próximo passo foi definir a lista de perguntas relevantes para aplicação na pesquisa. A fim de reduzir a extensão do questionário e ainda assim abordar todos os tópicos relevantes para o contexto de avaliação, a estrutura principal do questionário foi dividida em duas partes hierárquicas. A parte I consiste em sete grupos de questões obrigatórias que todos os participantes devem responder, e são destinadas a identificar qual domínio da QAI causa altas frequências de desconforto no participante. A parte II reúne as respectivas questões de aprofundamento de cada domínio da QAI. Ou seja, a parte I funciona como um filtro para o detalhamento da parte II, dispensando aqueles participantes que não indicam desconforto (e, portanto, estão confortáveis com o status de seu ambiente de trabalho) de passar por tais perguntas; assim como sempre que algum tipo de desconforto é detectado, a parte II é acionada permitindo coletar mais informações a respeito daquele domínio. Uma vez definida a hierarquia das questões, foram propostos itens de resposta e escalas de avaliação, assim como a plataforma on-line

que abriga o questionário e sua interface foram devidamente configurados para serem testados.
O questionário longitudinal elaborado foi testado separada e independentemente da estrutura de avaliação proposta, a fim de identificar pontos fracos e ajustes necessários antes da sua implementação. Os testes foram realizados com o objetivo de encontrar evidências de validação de conteúdo e aparente. Para a o teste de validação de conteúdo, o instrumento foi submetido à revisão de pesquisadores e especialistas da indústria de cada domínio da QAI para avaliar se o conteúdo a respeito das variáveis inerentes a cada domínio foi contemplado e se a forma como os tópicos foram abordados é adequada para gerar um diagnóstico consistente daquele domínio. Após a implementação dos ajustes recomendados pelos especialistas, o segundo teste avaliou a validade aparente do instrumento, no qual as questões propostas e seus respectivos itens passam por uma avaliação subjetiva para determinar se parecem lógicas, claras e apropriadas aos conceitos estudados, bem como testam a experiência do usuário com a plataforma on-line e sua interface. Duas rodadas de aplicação do questionário (grupos A e B) foram realizadas com grupos de voluntários, seguidas por uma discussão exploratória. O grupo A era composto por dez voluntários leigos, enquanto o grupo B era composto por seis pesquisadores da área com experiência em pesquisas de campo e aplicação de questionários. A versão final do questionário foi revisada com base nos comentários e observações indicadas no final deste processo. Finalmente, uma aplicação mais ampla do questionário longitudinal elaborado foi conduzida com funcionários do escritório em geral em um estudo piloto a fim de simular a aplicação real. O recrutamento dos participantes do estudo piloto foi feito através de listas e-mail institucionais, mídia social e outros, e conseguiu obter respostas de 115 voluntários em duas semanas de coleta de dados. Foi solicitado aos participantes que preenchessem o questionário considerando seu local de trabalho. Ao final, eles foram convidados a responder perguntas adicionais sobre o instrumento em si, avaliando o questionário quanto à sua organização, objetividade, clareza, legibilidade e compreensão de conteúdo, atribuindo a cada item uma pontuação de 1 a 5. Também foi solicitada sua opinião sobre a adequação dos tópicos abordados na pesquisa para avaliar a satisfação com a QAI do seu ambiente de trabalho, seguido de uma questão aberta para indicação de qualquer tópico ausente e/ou outra contribuição relevante. Este estudo piloto foi submetido e aprovado no Comitê de Ética em Pesquisa com Seres Humanos (CEPSH-UFSC) com Certificado de Apresentação de Apreciação Ética número 59892022.3.0000.0121. Dados de medição em campo não foram coletados nos testes do instrumento.

Conclusão

A avaliação do questionário pelos participantes na aplicação do estudo piloto indicou adequação do instrumento para medir a satisfação com a QAI em seu ambiente de trabalho, que obteve uma pontuação média de 4,75 de um total de 5 pontos. Os itens organização, compreensão do conteúdo, legibilidade, clareza e objetividade também alcançaram boas avaliações, com uma média mínima de 4,55 de 5 pontos possíveis. Explorando os dados obtidos na aplicação do estudo piloto, foram sugeridos indicadores de desempenho, bem como possíveis resultados complementares a serem extraídos da aplicação do instrumento, que podem ajudar na compreensão das particularidades do edifício e apoiar o processo de tomada de decisão, ajudando a identificar possíveis recomendações para a QAI e o aumento da satisfação do usuário. Com relação à estrutura do questionário, foram levantadas hipóteses a respeito da lista de desconforto apresentada na parte I. A primeira foi que, ao enfrentar a lista de possíveis situações vivenciadas na rotina de trabalho, geraria sensibilização dos participantes sobre a QAI no ambiente de trabalho e, portanto, traria também indicações de possíveis problemas com esses aspectos, antes despercebidos. De fato, as indicações desta sensibilização podem ser observadas a partir da diferença entre a ausência de taxas de desconforto (nenhum domínio desencadeado), atingindo apenas 8% do total da amostra, contra 81% dos participantes que atribuíram pontuação maior ou igual a 7 para a satisfação com a QAI na questão Q0. Ou seja, uma proporção maior (92%) indicou frequências médias a altas de desconforto com pelo menos um domínio da QAI na parte I do questionário, mesmo após classificar o ambiente com notas altas na Q0. No entanto, esse fato leva à segunda hipótese, de que a lista de desconforto poderia influenciar na criação de viés negativo em direção a uma avaliação de conforto geral mais baixa, uma vez que ela descreve situações desconfortáveis pedindo aos participantes que atribuam a frequência de experiência desses tópicos em sua rotina de trabalho. Nenhuma evidência de enviesamento negativo foi observada na amostra do estudo piloto, uma vez que as tendências de correlação entre a satisfação com a QAI (Q0) e a satisfação com o conforto geral (A21) foram positivas. Entretanto, estudos adicionais devem acompanhar este resultado a fim de verificar e evitar vieses na pesquisa. Em relação à análise estratificada proposta na parte I por tipo de layout (questão [1/7]) e tempo na estação de trabalho (questão [3/7]), a estratificação mostrou resultados diferentes entre as amostras avaliadas. Por exemplo, a proporção de domínios em desconforto (tanto combinados como individualmente) e nenhum desconforto frequente, bem como o nível de importância de cada aspecto da QAI variou entre os diferentes tipos de layout. Considerando que o questionário é anônimo e, portanto, não sendo possível agrupar as respostas de layouts com as mesmas características, os resultados obtidos no estudo piloto justificam manter a questão [1/7] na parte I, uma vez que ela pode ajudar a identificar pontos críticos específicos, auxiliando na sugestão de soluções por parte dos operadores e gerentes. O mesmo se aplica ao tempo na estação de trabalho, uma vez que os resultados mostraram uma tendência de redução da pontuação atribuída entre satisfação com a QAI e conforto geral de acordo com o aumento do tempo decorrido na estação de trabalho, principalmente em salas privadas. Quanto a possíveis indicadores de performance obtidos a partir do questionário proposto, foram sugeridos seis índices: Índice de Satisfação com a QAI (Q0) e Índice de Satisfação com o Conforto Geral (A21) como indicadores gerais para todo o escritório; e Índice de Satisfação Térmica (A8); Índice de Satisfação com a Qualidade do Ar Interno (A10); Índice de Satisfação Visual (A17); Índice de Satisfação Acústica (A20) como indicadores específicos da QAI. Também é sugerido um Índice de Gerenciamento de Instalações Prediais (A24). Além dos índices em si, a avaliação de domínios em desconforto pode ajudar a compreender seus efeitos combinados e entre domínios, fornecendo os dados necessários para investigações consistentes a partir de experiências da vida real. Além disso, nas questões abertas os participantes expuseram situações nas quais indicavam dificuldade em encontrar o equilíbrio entre a combinação de determinados domínios a partir da operação de sistemas e de características dos edifícios. Ainda que estas situações representem uma tarefa mais complexa de lidar para as equipes de gerenciamento, *insights* dessa natureza podem ser valiosos para o BPE, uma vez que se aproxima de problemas reais do ponto de vista dos ocupantes, auxiliando na identificação de boas e más práticas operacionais.

A análise crítica dos resultados do estudo piloto também levantou outras revisões importantes no instrumento. A questão da privacidade gerou atenção a partir dos resultados obtidos sobre o nível de importância de cada parâmetro da QAI (questão A26), principalmente sobre a privacidade acústica. Como a avaliação de privacidade só era acionada para aqueles participantes que indicavam trabalhar em escritórios que não possuíssem ambientes específicos para determinadas atividades (salas de reunião, foco e/ou atividades em grupo), os resultados foram muito restritos para serem comparados à questão A26, o que pode levar a interpretações equivocadas. Portanto, recomenda-se rever a seção de privacidade na ramificação do questionário, expandindo sua aplicação como aprofundamento obrigatório na parte II. Com relação aos itens de resposta, o ajuste da escala deve ser ponderado considerando o estabelecimento de uma escala de 5 pontos para avaliação de todas as questões. Este ponto de atenção deriva da diferença na proporção entre participantes que avaliaram a satisfação com a QAI no seu ambiente de trabalho com nota maior ou igual a 7 (Q0), e participantes que não indicaram nenhum desconforto (nenhum domínio acionado para detalhamento) na parte I. Estes resultados podem ser interpretados como conflitantes. Além disso, a distribuição de pontuação nas perguntas Q0 e A21 ficou concentrada entre 4 e 10, podendo ser uma evidência de que escalas mais amplas como 0 a 10 pontos sejam inadequadas para este tipo de avaliação. Este ponto também está relacionado à questão de vínculo do instrumento proposto com a pesquisa de clima organizacional através da Q0, que desencadeia a parte I da identificação de domínios. Considerando os resultados obtidos, deve-se avaliar o aumento da "nota de corte" da Q0 de 7 para uma pontuação mais alta, a fim de dar a mais participantes a oportunidade de compartilhar sua opinião e, portanto, fornecer um diagnóstico abrangente. Com relação aos itens de resposta, a possibilidade de ocorrência do viés de hábito foi identificada. Para mitigar essa possibilidade, sugere-se que os itens sejam ordenados aleatoriamente. Frequências mais altas de desconforto térmico por frio obtidas no estudo piloto sugerem a aplicação semestral (verão e inverno ou meses quentes e frios) necessária para aplicação do instrumento, a fim de evitar viés de memória recente. Essa diretriz deve ser prevista no escopo do módulo *Standard* da estrutura de avaliação proposta.

As limitações desta pesquisa consistem na impossibilidade da realização de estudos de campo nos quais as condições físicas ambientais pudessem ser medidas e monitoradas, derivadas das restrições de saúde e segurança impostas pela pandemia de COVID-19, em curso ao longo do desenvolvimento deste trabalho. O monitoramento de tais dados poderia contribuir com o teste dos instrumentos, uma vez que serviriam como uma verificação da realidade da percepção subjetiva dos ocupantes, auxiliando na interpretação dos resultados. Outra limitação deste estudo decorre da extensão da estrutura de avaliação proposta, que requer aplicação em um estudo de caso de longo prazo. Portanto, no âmbito desta pesquisa, apenas uma parte de todo o método de avaliação proposto pode ser testada - o questionário longitudinal. Com relação aos testes realizados para este instrumento, é reconhecido que os processos de validação requerem aplicações mais amplas. O esforço de testar o instrumento em um estudo piloto foi o de proporcionar um primeiro contato com participantes em geral (funcionários do escritório). Mesmo que os resultados obtidos tenham demonstrado a adequação do instrumento para medir a satisfação dos usuários com a QAI do ambiente de trabalho, testes apropriados de validade e confiabilidade devem ser conduzidos em futuras aplicações, a fim de consolidá-lo como um instrumento consistente para identificar a percepção dos ocupantes e oferecer um diagnóstico abrangente do edifício.

ABSTRACT

To ensure enclosed spaces with comfortable conditions and satisfactory for people, the indoor environment needs to be evaluated, which requires aggregating data to provide a picture of overall building performance. Recommendations for assessing Indoor Environmental Quality (IEQ) satisfaction point towards advanced methods in new and innovative approaches, suggesting assessing it from the combination of quantitative and qualitative data that provide empirical information to improve the indoor environment. This research aims to propose an assessment framework for user satisfaction with the workplace regarding Internal Environmental Quality for office buildings, focusing on a longitudinal survey to identify occupants' perception of IEQ-related issues for a comprehensive building diagnosis. In that matter, an assessment framework is proposed, focusing on occupancy phase of Building Performance Evaluation (BPE), intended to create a clear and gradual process of data collection for problem identification, implementation of necessary corrective actions, and further follow up for reevaluation. This continuous evaluation process aligns with BPE model, and not only allows long-term adaptation but, mainly, suggests also continuous improvement of user satisfaction with IEQ assessed parameters. The assessment framework consists of three main modules, designed to be performed on a mixed-method approach combining quantitative (physical measurements of the building's environmental parameters) and qualitative (user survey instruments) data, aiming at triangulation purposes. Within such context, this research focuses on developing a survey instrument (longitudinal questionnaire) to collect data regarding users' perception of IEQ. To reduce the questionnaire extent and yet address all relevant topics, the instrument' main structure was divided into two hierarchical parts: I – domain identification and II – detailing questions. The designed instrument was tested in order to identify weaknesses and necessary adjustments. Tests were conducted to gather evidence of content and face validity. A wider test application was carried in a pilot study with office employees in general to simulate the real application, which reached 115 volunteers. Participants evaluation of the questionnaire showed suitability of the instrument to measure IEQ satisfaction with their work environment, obtaining an average score of 4.75 out of 5 points. Exploring pilot study data obtained, performance indicators were suggested as well as possible complementary results to be extracted from instrument' application, that can assist understanding of building specific particularities and support decision-making process by helping to identify possible recommendations for IEQ and user satisfaction enhancement, for example data stratification by type of layout and time at the workstation. Critical analysis of pilot study results also raised other major instrument' reviews, such as setting all questions to be evaluated on a 5-point scale, privacy section, and randomization of items lists.

Keywords: Indoor Environmental Quality. User satisfaction. Office Buildings.

FIGURES SUMMARY

TABLES SUMMARY

ABBREVIATIONS AND ACRONYMS LIST

BOSSA-TL	Building Occupant Survey System Australia – Time Lapse
BOSSA-SS	Building Occupant Survey System Australia – SnapShot
BPE	Building Performance Evaluation
BUS	Building Use Studies
EMA	Ecological Momentary Assessment
ESP	Experience Sampling Program
HR	Human Resources
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
MWFH	Mandatory Work From Home
POE	Post Occupancy Evaluation
SHE	Sustainable and Healthy Environment

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1 INTRODUCTION

Humans spend 90% of their time in the enclosed shelter of buildings (HONG *et al.*, 2017; KLEPEIS *et al.*, 2001). In particular case of office buildings, prior to COVID-19 pandemics, workforce from service and knowledge driven economy used to spent nearly one third of their daily time at the office (ANTONIADOU; PAPADOPOULOS, 2017). Since buildings exist to serve human needs (ALTOMONTE *et al.*, 2020), people often behave proactively within their indoor environments seeking for comfortable personal conditions, which have consequences for building performance (HONG *et al.*, 2016). Human behavior indoors is based on how people use, perceive and react to their environment by interacting with the building (DAY; O'BRIEN, 2017), and it does involve decision-making processes that tend to be complex. In office buildings, recent research has shown that this process can embrace aspects beyond building design and technology until diverse characteristics of occupants such as personality traits (HONG *et al.*, 2020), habits or culture and factors such as leadership or organizational policy (HONG *et al.*, 2017), beyond physiological aspects (PIGLIAUTILE *et al.*, 2020; SCHWEIKER *et al.*, 2018). Such behaviors can affect both building energy consumption and Indoor Environment Quality (IEQ) significantly. Due to this close relation, a wide range of researchers now acknowledge that it is the people who occupy the spaces that have the power to determine the success or failure of a building (GRAHAM; PARKINSON; SCHIAVON, 2021).

Since improvements in office IEQ parameters can deliver large health and wellbeing benefits for employees, it may also bring, in turn, financial benefits for organizations (POLLARD *et al.*, 2021). When it comes to costs, building operation is far less expensive than salaries and benefits of employees: staff typically account for about 90% of a business' operating costs, meanwhile building rental takes about 9%, leaving energy costs with only about 1% (WORLD GREEN BUILDING COUNCIL, 2014). Also, recent studies have shown that environmental satisfaction have a positive relationship with job satisfaction, which is linked to important outcomes for employers such as job stress, employee benefits and salary, physical and mental well-being, and satisfaction with management (CHEUNG; GRAHAM; SCHIAVON, 2022). Therefore, building-related decisions must always ensure users' needs are provided, since choices made only to save energy will cost more than they will save if do not support users requirements for comfortable, functional, healthful and attractive spaces (ALTOMONTE *et al.*, 2020).

It is well known that the built environment is a complex system that spans among professionals, from architecture, engineering and facilities management, as much as it is a multidisciplinary field, extending from design to psychology, economics, planning, sociology and so on (LEAMAN; STEVENSON; BORDASS, 2010). In that matter, collaborations through both building and personal office management have high potential to combine in order to provide insights about staff satisfaction with the indoor environment (VISCHER, 2008). For instance, Human Resources are often responsible for employee evaluations such as job and environmental satisfaction, which might be a valuable source of information about which environmental features work well from users' perspective. On the other side, Facility Managers could act as the source of expertise about how to best maintain desired conditions, balancing against a range of corporate goals and budgets. Such information may be combined with other indicators to track building performance, and this collaboration needs to be ongoing through the life of the building (ALTOMONTE *et al.*, 2020). Despite monitoring and tracking performance overall is a widespread path in the Management field, having in mind that what can be measured can be improved, when it comes to commercial office buildings, the building itself is often not included in the key indicators of performance. According to Altomonte et al. (2020), the reason may be related mainly with the limiting language of conventional building indicators, which do not put people at the center of decision-making and can often overlook the influence of the built environment on occupants. Recent studies have been seeking for a comprehensive suite of occupant-centric indicators, which can help guide building design and operation to satisfy occupant demands and also quantify the influence of interactions on energy consumption and IEQ (LI; WANG; HONG, 2021). Therefore, to effectively monitor satisfaction in office buildings require improvements in defining what and when needs to be tracked and measured, and how to cross and express the results.

The performance concept and framework for systematic evaluation of the built environment is defined as Building Performance Evaluation (BPE) (PREISER, W F E; HARDY; SCHRAMM, 2017). It was introduced for the first time by Preiser and Schramm (1997) and considers the entire life cycle of buildings throughout phases and feedback loops. This resource helps architects, building owners, and facility managers understand the implications to the facilities that they design, built or commissioned. Post-Occupancy Evaluations (POEs) consist of phase five out of six building life cycle phases (planning, programming, design, construction, occupancy, and future adaptability of the structure), and focuses on how buildings function after they are occupied. It is defined as a general approach of obtaining feedback about a building's performance in use, including energy performance, IEQ, occupants' satisfaction, etc. (LI; FROESE; BRAGER, 2018).

Satisfaction or dissatisfaction levels perceived by users from their workspace is a notion that has guided building evaluation since its earliest efforts, referring to the processes whereby users know and judge their physical environment. Such evaluation studies aim to determine the extent to which certain environmental characteristics affect users satisfaction, and have been carried out in offices since the 1980s (VISCHER, 2008). In real-life scenarios, occupants would perceive the environment as a whole, making it extremely difficult to predict their satisfaction with the building (JIN *et al.*, 2021). Many efforts for improvements have been taken over recent decades in POE studies, seeking to close the loop between building design and performance, based on quantitative feedback from occupants (CANDIDO *et al.*, 2016). By allowing an exploration of relationships between occupant perception and behavior with building use also allows an opportunity for optimization of the indoor environment, as well as more informed decisions about building operation and future design. Directions for the next buildings' IEQ assessment during occupancy phase points out that evaluation methods may now move towards new and innovative approaches, either from one-off to continued, from high-level to detailed, from researchers-oriented to owners and occupants-oriented, from independent to integrated (LEE et al., 2020). That is, IEQ performance can be evaluated by both qualified and quantified data collection methods which provide empirical data to improve indoor environment guided by user-centric approaches (JIN, Q., WALLBAUM, H., RAHE, U., & FOROORAGHI, 2019). The important consideration is to make it possible for people to experience environmental conditions that they prefer, which are associated with better outcomes for them but also for organizations (ALTOMONTE et al., 2020). Since the role of post-occupancy studies on BPE is to bring user feedback from occupancy phase for all building stakeholders, beyond the needed comprehension of multi-domain influence on user's perception and behavior (MAHDAVI *et al.*, 2020; SCHWEIKER *et al.*, 2020), the interactions between the building and its users should be followed by corresponding tools to provide in-depth information on occupant indoor experiences and the way how users tend to use buildings.

Moreover, another relevant aspect comes from the Brazilian construction context, which lacks an evaluation system that investigates user satisfaction, nor has a formal satisfaction survey instrument for this purpose. Such lack also reflects the smaller number of Brazilian buildings that seek environmental certifications during use and operation phase that score on IEQ-related requirements, since regular application of user surveys is mandatory for its achievement. Another reason is that the main survey instruments currently available charge their application, and therefore represent another barrier for wide implementation. From this overview, stands the gap for a more advanced assessment framework method, combining current technology on performance measurement protocols and data analysis with a comprehensive scenario of user perception from the workplace, that should be consistent and yet flexible enough to adapt to lifetime of buildings. Within this context, methods and instruments to assess user satisfaction should be improved, or even fully developed when Brazilian context is considered, in order to enhance communication between different stakeholders and putting users at the center of building design, technology and service, motivating their satisfaction to the environmental quality indoors.

1.1 RESEARCH AIM

This research aims to propose a longitudinal survey questionnaire to identify occupants’ perception of IEQ-related issues in office buildings, within an assessment framework for user satisfaction with the workplace.

1.2 SPECIFIC AIMS

Specific aim related to the assessment framework is to design a long-term process-oriented structure to (i) identify possible recommendations for IEQ and user satisfaction enhancement by providing a better understanding of building specific particularities and supporting decision-making process.

Specific aims for the occupant survey instrument are the following:

(ii) To optimize survey response rates by designing a brief and user-friendly survey interface that encourages consistent answers and minimizes participant fatigue.

(iii) To gather preliminary validity evidence for the survey instrument by conducting a pilot study with targeted participants (office employees) to assess its suitability for measuring satisfaction with the indoor environmental quality (IEQ).

(iv) To analyze occupant survey data and use the results to inform the development of key indexes that can be used to interpret and understand the impact of IEQ on occupant satisfaction.

1.3 RESEARCH STRUCTURE

This research is divided in five chapters. Following introduction and research aims, is chapter 2 with literature review. In chapter 3 is introduced the developed assessment framework, presenting the proposed structure and solutions created to achieve mentioned aims within building assessment. Afterwards, in chapter 4 is presented the longitudinal questionnaire development process as well as its testing processes and results obtained with the conducted pilot study. Finally, conclusions are presented in chapter 5.

2 LITERATURE REVIEW

Literature review carried for this research was organized as follows. First, a brief introduction of Building Performance Evaluation process model during occupancy phase is presented on item 2.1. Further, Indoor Environmental Quality is introduced in section 2.2, presenting existing and suggested future methods for objective measurements of IEQ variables in item 2.2.1 and the main occupant satisfaction survey tools in item 2.2.2. Next, evaluation of building IEQ is discussed on item 2.2.3, showing examples of practical tools aligned with the objectives of this research. A model to measure occupant satisfaction with building IEQ is presented on item 2.2.4; as well as recent findings regarding multi-domain studies on item 2.2.5. Section 2.3 presents examples of innovations observed recently in building IEQ evaluation. The future of work environments is also discussed, considering post-pandemic scenarios, in section 2.4. At last, discussion and final considerations for the assessment framework development are presented in section 2.5.

2.1 BUILDING PERFORMANCE EVALUATION: INTEGRATION AND FEEDFORWARD

According to Preiser, Vischer (2006), BPE framework was developed in order to broaden the basis for POE feedback to include a wider range of stakeholders and decision-makers who influence buildings beyond architects and engineers, but also investors, owners, operators, and most importantly, the actual users who occupy the building. Through process-oriented evaluations, the goal of BPE is to improve the quality of decisions made at every phase of the building life cycle. A meaningful evaluation focuses on the values behind the goals and objectives of all stakeholders. Therefore, making expected building performance requirements explicit, and comparing the actual performance with that which was initially stated is the basis of performance concept in BPE (PREISER; HARDY; SCHRAMM, 2017).

Beyond life cycle phases, BPE model emphasizes a process with interdisciplinary teams. And the ‘feedforward’ aspect between teams and phases may be the more important step of BPE (PREISER; HARDY; SCHRAMM, 2017). Many of the building problems identified after occupancy have been found to be systemic:

information engineers did not have about building use; changes made after occupancy that the architect did not design for; or facilities staff's failure to understand how to operate building systems (PREISER; VISCHER, 2006). This means that each phase and teams are indispensable components that must be considered in a circular arrangement, by either generating databases or providing access to prior findings. Feeding forward information and knowledge helps to streamline all stages of building design and management, including avoiding common mistakes caused by insufficient information and inadequate communication among building professionals at different stages (PREISER; HARDY; SCHRAMM, 2017).

During occupancy phase, BPE is activated in the form of POEs to provide user feedback on what works in the facility and what needs improvement, as well as identify performance issues. An integrated BPE approach requires subjective tools to be matched by building metrics. Leveraging occupants as sensors to capture IEQ conditions is valuable, but the addition of measured environmental conditions and attributes that define physical environments are equally critical to understand building occupant comfort, satisfaction, health and performance (PREISER; HARDY; SCHRAMM, 2017). Therefore, POE methods can broadly include different approaches for data collection. Most common are presented in Table 1 and Table 2. Regarding IEQ, standardization of measurement and performance evaluation should follow a systematic methodology, known as "protocols". Li et al. (2018) state-of-the-art review and practice on post-occupancy phase studies points a list of 16 existing POE protocols, e.g., Post Occupancy Review of Building Engineering (PROBE) (CIBSE, [*s. d.*]), Smart Controls and Thermal Comfort (SCATs) (NICOL, J. F.; MCCARTNEY, 2000) and Health Optimization Protocol for Energy-efficient buildings (HOPE) (BLUYSSEN; ARIES; VAN DOMMELEN, 2011). Authors highlighted as a remarkable protocol the Performance Measurement Protocol (PMP) for Commercial Buildings jointly developed by ASHRAE/CIBSE/USGBC (ASHRAE, 2010), which provide a set of instructions to guide accurate data collection and appropriate comparison of measured energy, IEQ and water performance of commercial buildings. This protocol provides three different levels of evaluation (basic, intermediate, and advanced), representing different ranges of accuracy regard temporal and spatial resolution and even cost of implementation.

Table 1 - POE methods for objective data collection.

Objective data: physical measurements	
IEQ measurements	
Thermal condition	sensors/meters for temperature, relative humidity, air velocity; infrared thermal imaging.
Lighting	illuminance and luminance meters; high dynamic range (HDR) imaging cameras.
IAQ	sensors for CO2, TVOC, formaldehyde, CO, respirable particles.
Acoustics	sound level meters; reverberation test.
Energy and Water	
assessed via audit, sensors, meters or bills.	

Source: (LI; FROESE; BRAGER, 2018)

Table 2 - POE methods for subjective data collection.

Subjective data: occupant survey methods
Occupant survey
standardized occupant satisfaction; thermal comfort; visual comfort; customized surveys. Surveys can include questions that inquire about "how do you feel right now" or "general satisfaction".
Interviews
structured or semi-structured interviews; group meetings with occupants and experts.
Walkthrough
expert tours to identify issues, along with photo/video recording, design/condition checklists, and observation forms.

Source: (LI; FROESE; BRAGER, 2018)

Next section focuses on aspects related to Indoor Environmental Quality throughout occupancy phase that are necessary to constitute an integrated approach to BPE.

2.2 INDOOR ENVIRONMENTAL QUALITY IN OFFICE BUILDINGS

According to ASHRAE TC 1.6 (Terminology), Indoor Environmental Quality (IEQ) is defined as a "perceived indoor experience about the building indoor environment that includes aspects of design, analysis and operation of energy efficient, healthy and comfortable buildings". Environmental conditions encompasses four main parameter domains: a) indoor air quality, e.g., smells, irritants, pollutants, outdoor air and ventilation; b) thermal comfort, regarding air temperature, humidity, mean radiant temperature and velocity; c) visual comfort, such as view, illuminance and reflection; and d) acoustical comfort, e.g., control of unwanted noise, vibrations and reverberations (ORTIZ; KURVERS; BLUYSSEN, 2017). In other words, it consists of a set of basic parameters defined from design stage until use and operation phase, being under direct influence of the inherent process of decision-making on building operation. The result of this multidisciplinary process aims to reach habitability conditions of built environments.

The traditional pathway between IEQ research and practice in the built environment domain has been via building codes and regulatory documents such as standards (CHEUNG *et al.*, 2019). Either international or country-specific, building regulations usually set prescriptive limits and/or basic conditions to be reached out on design stage and maintained during building occupancy for each described parameter, which is crucial for ensuring sufficient levels of IEQ to promote healthy and comfortable indoor environments. According to Mahdavi et al (2020), implementation of building codes prescribed conditions typically involve both effectiveness and efficiency considerations, i.e. effective attributes of design in view of IEQ to be realized in an efficient manner in terms of energy and resource use. Other forms of assessment procedures like voluntary building evaluation schemes, such as WELL (IWBI, 2020) and Fitwel (FITWEL, 2021), which are specifically aimed at promoting the health and wellbeing of commercial building occupants (POLLARD *et al.*, 2021), also play the role of guidelines, as most of them require at least compliance with standards for building evaluation. These voluntary certification schemes have served as powerful market drivers and motivators for building owners and operators to reach and even to exceed performance guidelines (PARKINSON; PARKINSON; DE DEAR, 2019). On the following items, building measurements, occupant surveys, IEQ performance and satisfaction evaluation are presented and discussed.

2.2.1 Objective data: physical measurements

As presented in Table 1, physical measurements of the built environment embrace a large set of data to be extracted from the evaluated building. Efforts have been made regarding physical indoor climate measurements to be collected by an integrated suite of IEQ instruments. From the first mobile instrumented cart created in 1985 at University of California, Berkeley, until evolvements to sophisticated wireless carts, used as portable wireless monitoring system (PWMS) to support commissioning, the idea of an IEQ cart has been widely adopted later in many studies and protocols (LI; FROESE; BRAGER, 2018). BOSSA Nova cart, for instance, from University of Sidney IEQ Lab, registered air and globe temperatures, air velocity, relative humidity, carbon monoxide, carbon dioxide, total volatile organic compounds (VOCs), formaldehyde, ambient sound and illuminance in three-minute interval samples with time-stamps to enable integration between measurements and occupant surveys (CANDIDO *et al.*, 2016).

However, sensor accuracy and calibration have been for long-time critical points of objective measurements, beyond their own cost. Also, the labor associated with deploying sensors across a large building and then analyzing the vast amount of data can easily become impractical (HEINZERLING *et al.*, 2013) due to spatial and temporal variance between floors as well as across floor plan at Heating, Ventilation and Air Conditioning (HVAC) zone level: perimeter *vs.* core zones, East *vs.* West zones in morning and afternoon, North *vs.* South zones in summer *vs.* winter (PARKINSON; PARKINSON; DE DEAR, 2019). That leads most current measurement tools to be often inadequate as they generate unrepresentative sampling strategies, considering just a single time-point in a limited number of locations. Such evaluations cannot adequately represent spatial and temporal variations in IEQ that may exist throughout a building (POLLARD *et al.*, 2021).

Recent technological innovations developing the Internet of Things (IoT) and smart buildings containing distributed networks of wireless sensing devices (e.g., sensor technologies, wireless communication protocols, data mining analytics), present new opportunities to provide insights and improvements, which could make measuring building parameters become a much less labor-intensive process. Due to such innovations, spatial and temporal sampling problems have the chance to be overcome, generating unprecedented insight into IEQ performance analysis of office buildings. Such networks, comprised of easy-to-deploy, cost-effective sensors, replace or increase traditional hard-wired systems that are often heterogeneous in implementation and too coarse in resolution to properly capture variability of IEQ inside a building (PARKINSON; PARKINSON; DE DEAR, 2019).

Regarding concerns over the accuracy of low-cost continuous measurement devices, Parkinson; Parkinson; De Dear (2019b) argue that it is often ignored the ability of pervasively deployed devices to provide insight into IEQ variability in both the spatial and temporal dimensions, since multiple devices placed across a floor plan with enough accuracy provide a more representative picture of indoor conditions experienced by occupants than a single-point measurement with laboratory-grade equipment mounted on a mobile cart (PARKINSON; PARKINSON; DE DEAR, 2019).

As an example of applied innovation on IEQ monitoring, authors presented Sentient Ambient Monitoring of Buildings in Australia (SAMBA), which is a monitoring device developed by University of Sidney IEQ Lab that integrates a low-cost suite of sensors of environmental variables and modest data-processing capabilities to autonomously measure key IEQ indicators (PARKINSON; PARKINSON; DE DEAR, 2019).

IEQ parameters targeted by SAMBA were guided by the requirements for NABERS Indoor Environment rating scheme (further presented in section 2.2.3.1) and are listed in Table 3. Sensor performance requirements were scaled to the application, allowing substantial reductions in both hardware costs and end-use operational costs. Apart from cost, performance (accuracy, range, sensitivity, resolution, calibration drift), power requirements, output type, interface protocol, and form factor were key elements for sensor selection. Also, on-site installation was designed as a plug-and-play procedure, with no prior knowledge required. Minimum recommended SAMBA density is five devices per floor, or one per air conditioning zone, whichever is higher (PARKINSON; PARKINSON; DE DEAR, 2019). Permanent placement within the occupied zone enables both spatial sampling across the building's floor plan and longitudinal measurements through time to characterize the environmental conditions experienced by occupants of office buildings. Resultant data is wirelessly communicated to a centralized web service named "IEQAnalytics", where it is possible to visualize all measured IEQ parameters and calculated indices in real-time. Data is presented alongside operational guidelines in order to calculate compliance time over the past 3-months with relevant IEQ standards in an intelligible and appealing format even to non-experts, beyond building owners and facility managers. The main dashboard view consists of five panels: real-time averages, displaying the latest 5-min measurements averaged over all the SAMBAs on the selected building floor; compliance times; recent histories; alerts; and noncompliant parameters, which are flagged in the alerts panel whenever occur over the last three hours. Each entry indicates the zone and the exact time at which the exceedance occurred, as well as a link to view the associated measurements. Weekly reports summarize the building performance over the four IEQ domains. These contain compliance statistics, total number of alerts, and highlights of problem areas encourage more detailed follow-up diagnostics.

Table 3 - List of sensors included in SAMBA, and their performance specifications.

Parameter	Sensor type	Range	Resolution
Air temperature	NTC thermistor	0–50 °C	0.1 °C
Relative humidity	Capacitive	5–95%	0.1%
Globe temperature	NTC thermistor	0–50 °C	0.1 °C
Air speed	Bi-direction. thermal anemometer	0–1 m/s	0.01 m/s
Sound pressure level	Electret microphone	40 to 90 dBA	0.1 dBA
Illuminance	Broadband photodiode	0 to 20.000 lx	1 lx
Carbon dioxide (CO2)	Nondispersive infrared	0–5.000 ppm	1 ppm
Carbon monoxide (CO)	Electrochemical	0–50 ppm	0.1 ppm
Formaldehyde (HCHO)	Electrochemical	0–2 ppm	0.01 ppm
Total volatile organic compounds (TVOC)	Photoionization	10–2000 ppb	10 ppb

Source: (PARKINSON; PARKINSON; DE DEAR, 2019)

Therefore, as a scalable solution to comprehensive assessments of building performance, it can improve quantitative understanding of IEQ issues and occupant satisfaction, health, wellbeing, and performance. Nevertheless, there is currently a lack of guidance on sampling procedures or measurement protocols to ensure reliable representation of measured IEQ parameters, since existing building standards and guidelines were not developed for technologies enabling continuous measurement of IEQ parameters (PARKINSON; PARKINSON; DE DEAR, 2019). Analytical techniques for robust time-series IEQ data and how to effectively visualize and communicate the results are also missing discussion, since the challenge to analyze and synthesize large amounts of data still remains.

2.2.2 Subjective data: occupant satisfaction surveys

POE evaluations of workspaces also rely on occupant satisfaction surveys to understand how well a building is functioning, since occupants seem to detect and report failures of systems which lead to discomfort (WAGNER; BRIEN, 2018). These surveys are responsible for collecting qualitative data on occupants' subjective evaluations of the indoor environment of their workplace. Research tools were developed in order to collect user responses through extensive paper questionnaires. Nowadays web-based tools like SurveyMonkey (SURVEYMONKEY, 2021), Qualtrics (QUALTRICS XM, 2021) and Google Forms (GOOGLE, 2021) reduce labor involved in creating, distributing and analyzing survey outcomes.

Standardized occupant satisfaction surveys for data collection were developed, regarding individual ratings of thermal comfort until overall satisfaction with the indoor environment. Most of them have been enhanced to become online web-based tools, enabling not just automatic deployment of the outcomes, but mainly gathering subjective data for building evaluations in large databases. Creation of such databases support benchmarking buildings, using occupant responses to determine the “typical” space and adopting it as performance reference point. Benchmark scores can be used to compare buildings with others, track the success of a space over time and help diagnose strengths and weaknesses in building operation (GRAHAM; PARKINSON; SCHIAVON, 2021).

Although there is no universally standardized protocol, two out of the most widely used occupant satisfaction surveys are a) Building Use Studies (BUS) methodology; and b) Centre for the Built Environment Occupant Survey (CBE IEQ survey), from University of California, Berkeley. Their extensive databases from several years of building surveys enable benchmarking, comparison and further building analysis (LI; FROESE; BRAGER, 2018). There are also c) Building Occupant Survey System Australia (BOSSA), from University of Sidney; and d) Sustainable and Healthy Environment (SHE), from Melbourne University. Each one is briefly presented next.

2.2.2.1 Building Use Studies

Original BUS questionnaire for occupant feedback was first developed in 1985 as part of the research project *The Office Environment Survey* (WILSON et al., 1987)*,* a decade in which international interest in Sick Building Syndrome (SBS) was highlighted. At the time, the tool consisted in a sixteen pages paper-based document and the survey covered a total of 4,300 office workers in 50 commercial buildings across the United Kingdom. In 1995, a simplified version of the questionnaire was developed to be used as one of the analysis tools in the PROBE series of post-occupancy surveys, giving rise to the standard two-page questionnaire (USABLE BUILDINGS, 2020). Since then, BUS methodology has been used to analyze building performance from user perspective in many countries, having its questionnaire translated into 17 language versions (ARUP, 2020).

BUS methodology aim is to gather objective occupant answers in the shortest possible time. Estimate questionnaire completion time is 5 to 15 minutes, and users anonymously rate the building's performance through a questionnaire with seven-point scale answers. Questionnaire also includes investigation of aspects related to health, perceived comfort, personal control and estimated self-reported productivity (GOSSAUER; WAGNER, 2007). Survey outputs are recorded in a unique database and the platform enables building comparison with other similar typologies, as illustrated in Figure 1, showing overall satisfaction with summer building conditions (top) compared to a reference sample by type of use or geographic region (bottom) from BUS method database. Qualitative data from surveys are also stored, and respondent's comments are sorted alphabetically by question type. Since user feedback is the key issue in building monitoring from BUS methodology, it is currently cited as a user satisfaction assessment tool accepted by building certification programs such as NABERS (further presented in topic 2.2.3.1) and WELL certification program (LI; FROESE; BRAGER, 2018).

2.2.2.2 CBE Occupant Survey

CBE Occupant Survey was developed in 1999 and has been applied in over a thousand buildings, with more than 100,000 individual responses from occupants (CBE, 2021). Protocol consists of an online web-based questionnaire (Figure 2) that assesses occupant satisfaction in relation to parameters including thermal comfort, air quality, acoustics, lighting, cleanliness, spatial layout and office furnishings in 10 sections. An integrated branch structure allows to collect more detailed data only when applicable, which avoids overloading respondents with inappropriate questions for their context. Whenever there is an indication of any degree of dissatisfaction, a set of branching questions shows detailed and specific feedback. These branching questions are checkbox and open-ended response types that aim to understand the reasons for dissatisfaction (GRAHAM; PARKINSON; SCHIAVON, 2021). Application is anonymous and voluntary, and estimated filling time is about 10 minutes. Outcomes are presented in automated reports, which also allows benchmarking with similar typologies from the CBE database. CBE Occupant Survey is widely accepted as a user satisfaction assessment tool by building certification programs such as LEED and WELL, and ASHRAE/CIBSE/USGBC PMP for Commercial Buildings also recommends using this survey for full POE assessments.

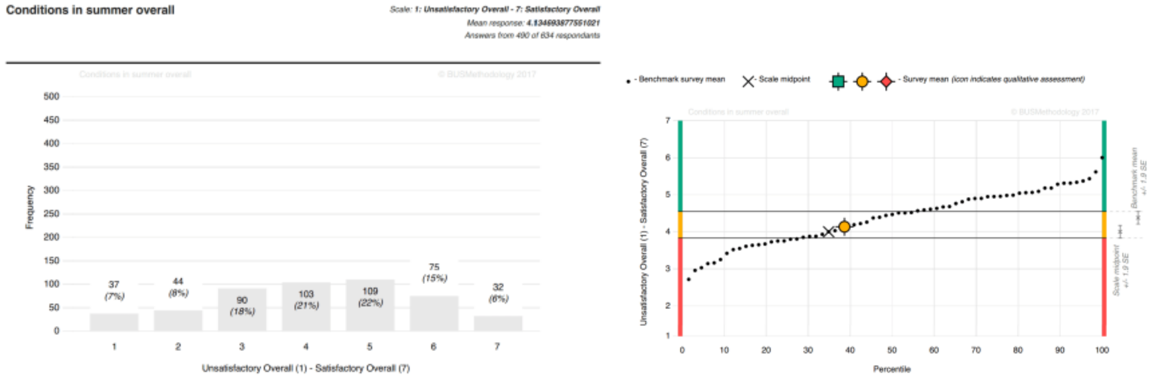
2.2.2.3 Building Occupant Survey System Australia

The Australian Research Council with building science researchers at two universities and a group of stakeholders (building owners, design and engineering firms, office tenants and building rating schemes) from the Australian commercial buildings sector funded the Building Occupant Survey System Australia (BOSSA) project in 2011 (CANDIDO *et al.*, 2016).

The whole system comprises three distinct components. BOSSA Time-Lapse is the first, which consists in a conventional POE occupant web-based survey tool, with summative questions regarding overall satisfaction with spatial comfort, indoor air quality, individual space, thermal comfort (season integrated), noise distraction and privacy, visual comfort, connection to outdoor environment, building image and maintenance. Survey was developed on an integrated and flexible branching structure, with thirty-one-question questionnaire with possibility to expand to include modules focusing on specific topics related to IEQ. Second, there is BOSSA Building Metrics, which is oriented to the building's facilities manager. Basically, it consists in systematically documenting details about design (e.g., floor plans, year of construction and/or retrofit, net-rentable area, number of floors), fit-out (e.g., lighting, shading) and buildings services engineering systems (e.g., HVAC system type, control, temperature set-points). And third, BOSSA Snap-Shot (Figure 3) attempts to match subjective and objective IEQ assessments. The so called "right-here-right-now" questionnaire should be applied with instrumental measurements on key IEQ variables (through IEQ Lab's BOSSA Nova cart, previously mentioned in item 2.2.1), enabling identification of possible IEQ-related issues identified by building occupants during the BOSSA Time-Lapse surveys. This approach allows quantitative analysis of causal associations between IEQs and the subjective evaluations of those qualities by the occupants (CANDIDO *et al.*, 2016).

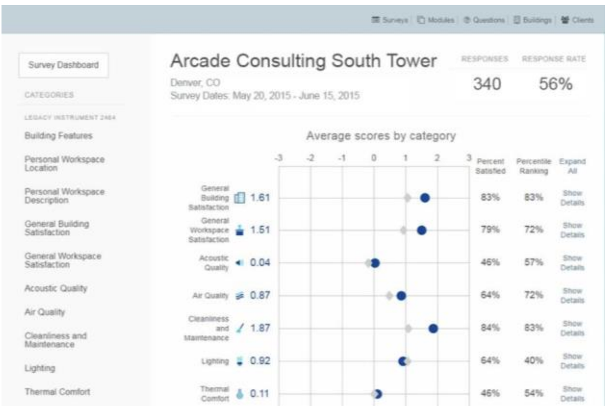
BOSSA survey results are presented in four summative indices focusing on characterizing the overall building performance: work area comfort, building satisfaction, productivity and health, and were derived from all nine IEQ dimensions differently weighted according to the magnitude of influence on each index. Statistical analyses were based on the fifty buildings from the BOSSA database until publication date, which were broadly representative of Australia's central business district office stock (CANDIDO *et al.*, 2016). The BOSSA system is NABERS IE endorsed, as well as Green Building Council of Australia (GBCA) and NZ Green Building Council (BOSSA SYSTEM, 2021).

Figure 1 - BUS methodology survey results and benchmarking.



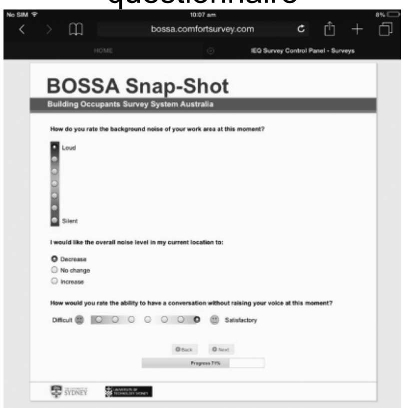
Left graph shows the answer frequency obtained. Right graph benchmarks the result with similar building typology. Source: (BUS METHODOLOGY, 2021)

Figure 2 - CBE Occupant Survey report screen.



Source: (CBE, 2021)

Figure 3 - Presentation screen of the BOSSA Snap-Shot questionnaire



Source: (CANDIDO et al., 2016)

2.2.2.4 Sustainable and Healthy Environment

Sustainable and Healthy Environment (SHE) is the latest occupant survey tool, launched in 2020 from Melbourne University, therefore little information is available. In addition to user satisfaction, this survey differential consists of data collection regarding personal, organizational and environmental variables that can affect both physical and emotional health, and self-reported productivity (SHE, 2020). Since the innovative survey focuses on health and organizational matters beyond IEQ, it is currently mentioned as a user satisfaction assessment tool accepted by health and wellbeing building certification programs such as WELL.

2.2.2.5 Challenges in Evaluating IEQ through Occupant Satisfaction Surveys

A few issues remain on IEQ evaluation from occupant satisfaction surveys. Considering that any survey outcome depends on occupants' subjective evaluation of the built environment, flaws are potentially expected as participants are subject to many types of bias unrelated to the built environment itself. Ambiguous factors such as organizational climate in the workplace, staff morale and a wide range of personal issues all potentially exert influence over how an office population rates their workplace environment (PARKINSON; PARKINSON; DE DEAR, 2019). Beyond that, the fatigue cost of having most of any building's population to spend time filling in a questionnaire is often seen as a major obstacle, therefore employers are often reluctant to initiate them due to productivity concerns (POLLARD *et al.*, 2021). And as much as the objective measures, satisfaction surveys are also typically conducted at a single point in time and fail to consider variations in occupant satisfaction over time. On the other hand, increasing survey frequency also increases potential for survey fatigue. There are also problems around contextualizing user responses and extracting meaningful insights from occupant feedback. That point reinforces that subjective assessments must be combined with objective measurements in POE evaluations, which are considered a "reality check" on the subjective responses (PARKINSON; PARKINSON; DE DEAR, 2019). Even more, the advantage of combining measures with surveys is a more holistic view of the relationship between occupants and buildings (GRAHAM; PARKINSON; SCHIAVON, 2021).

2.2.3 Building IEQ evaluation in practice

Findings from both objective and subjective data collected could be integrated into IEQ models or indices, which combine observed effects by applying weighting coefficients according to the assumed relative impact on overall occupant satisfaction (PARKINSON; PARKINSON; DE DEAR, 2019). General aim of IEQ models is a single, summative IEQ evaluation and the accuracy, relevance and applicability of such scoring systems depend heavily on the quality of the objective and subjective assessment data that is collected (HEINZERLING *et al.*, 2013). Apart from an overall IEQ building score, an alternative evaluation of IEQ parameters consists in fragmentation of categories, taking specific expertise standards as references (e.g., ISO 7730-2006, ASHRAE 55-2017, ISO 17772-2018, EN 16798-2019) and certifications (LEED, BREAM, WELL), which have mostly a single-domain character. Mahdavi et al. reviewed current state-of-art IEQ evaluation approaches and indicated that it tends to be mono-dimensional, and often overlooks the occupant's IEQ evaluation (MAHDAVI *et al.*, 2020). According to Parkinson *et al.* (2019b), several criticisms have been levelled at these and other IEQ models due to the presumed linearity in relationships between IEQ factors, which ignore interaction effects, and lack of standardized measurement protocols.

Challenges for supporting building performance regarding occupants can be related to the lack of easily accessible sensing techniques to collect the indoor environment and occupant data. Beyond that, many of the existing metrics are not designed from an occupant' point of view, consisting mostly of indoor environmental metrics, increasing the challenge to quantify the scale and extent of the indoor environment impacts (LI; WANG; HONG, 2021). For instance, a recent study examined the measurement characteristics of CBE Occupant Survey from its 20-year resulting database. Results showed that the current survey seems to successfully measure occupant satisfaction, but data analysis also suggested the need to design several new survey items that address what is working within a space, occupant preferences, wellbeing, job satisfaction, and the need for and perceptions of control, privacy, and personalization (GRAHAM; PARKINSON; SCHIAVON, 2021). Under this context, building performance evaluation has become a multidimensional target, with considerations for occupant comfort and wellbeing becoming essential. As the sensing technologies evolve, indicators from occupants should also take into consideration individual and group diversities to achieve a deeper understanding of performance (LI; WANG; HONG, 2021). Therefore, the establishment of a standardized measurement protocol, as well as clear articulation of how the data is used to improve IEQ performance are important and raises the need for future studies to describe and evaluate those new forms of interactions.

Next items present two selected tools for building IEQ evaluation which align to the main objectives of this research: the first as an example of an Australian rating system focusing on the building's operation phase, with a specific scope for benchmarking indoor environmental performance for office buildings; and the latter as an example of a usable tool to deliver comprehensive information to help operational decision-making process by analyzing building's IEQ profile.

2.2.3.1 National Australian Built Environment Rating System - NABERS

National Australian Built Environment Rating System (NABERS) assesses in use buildings performance for Energy, Water, Waste and Indoor Environment (IE) scopes, relying on building monitoring during operation phase. NABERS ratings are valid for twelve months to ensure that the result represents the current operating performance of the building, enabling results comparison between either the same building over time and similar buildings typology. Office typology benchmarking, for instance, takes into consideration location, area, occupied hours, occupancy density and number of existing computers. From a database available at the program's website (NSW DEPARTMENT OF PLANNING INDUSTRY AND ENVIRONMENT, 2020), there are currently more than 3,000 classified buildings across Australia, of which office typology accounts for 87%. Among certification scopes, Energy is the most frequent, with 62% of evaluated buildings. IE takes only about 4% and currently is only available for commercial office buildings. As the main building certification schemes, NABERS rating system is also segmented into building type (core and shell scope *versus* whole building), which is helpful when comparing different building occupation and classification results.

Indoor Environment certification scope requires objective measurements from air quality, lighting, temperature, and thermal and acoustic comfort, with detailed testing protocols and rigorous auditing procedures. Up to date of this research, application of user satisfaction surveys was carried out only in two occasions for Tenant type classification, which evaluates individual workspaces within an office building (e.g., rooms or private floors) and is intended for those occupants who can define the internal layout and materials, as well as lighting and indoor noise levels. No information was found on how user satisfaction is addressed, although according to Li, Froese and Brager (2018), BUS method is an integral part of the NABERS assessment.

2.2.3.2 Healthy Buildings and Energy Support Tool – H-BEST

Differently from NABERS, which consists of a rating scheme with strict protocols provided by a third party, the Healthy Buildings and Energy Support Tool (H-

BEST) was designed to provide usable point-of-entry for users and deliver comprehensive information. The project was developed in partnership between the United States Department of Energy's Federal Energy Management Program and Pacific Northwest National Laboratory (PNNL), launched in 2021 after a three-year development and field validation (PNNL, 2021).

Figure 4 - H-Best occupant survey input screen.

Step 3. Survey Data | Return to Instructions | Step 4

3. **Enter the following data from the occupant survey in the highlighted cells. Check the warning messages on the right.**

#	In a typical week, approximately what portion of your work time do you spend at the locations listed below? Your total time must equal 100%.	% at your desk in your primary work location	% in conference/meeting rooms in your primary work location	% working from home	% at other locations (client locations, other buildings on campus, work travel)
1	Responses:	76	9	12	3

#	When working in your primary work location, what kind of individual workspace do you primarily use?	An enclosed single-person office	An enclosed multi-person office	A workspace or cubicle where all dividers are high enough that you cannot see over when standing	A workspace or cubicle with some dividers that you cannot see over when seated	Open workspace with no dividers or dividers that you can see over when seated	None of the above
2	Responses:	16	2	76	4	0	2

#	Please indicate your typical state of comfort in your primary workspace for each season. Please select NA if you do not work during that season, have not worked during that season yet, or cannot remember.	Too warm	Somewhat too warm	Comfortable	Somewhat too cool	Too cool	NA
3	Spring	10	15	52	8	9	6
	Summer	20	22	33	9	8	8
	Autumn	4	15	56	9	8	8
	Winter	3	11	45	17	20	4

#	Which of the following air quality issues do you experience in your primary workspace. Select all that apply.	Odor	Stuffiness	Too dry	Too humid	Dust or allergens	None
4	Responses:	47	57	14	10	59	18

#	How satisfied are you with the electric (overhead and task) lighting in your primary workspace?	Very dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Very satisfied
5	Responses:	12	18	14	25	31

Source: (GITHUB - PNNL/HBI H-BEST, 2021)

The spreadsheet-like tool is aimed not only at building owners, managers and operators, but also for energy and sustainability managers. To integrate health factors with energy efficiency in the decision-making process, the tool analyzes building's IEQ profile and helps identify costs and benefits of improvements. Inputs include mandatory IEQ measurements for air quality, thermal comfort and lighting, but can also comprise a suggested nine-question occupant survey data, illustrated in Figure 4. Additional organizational data such as average employee salary can help assign monetary values to productivity improvements. Outputs consist of an automated IEQ analysis to identify improvement measures. There are approximately 60 recommendations, ranging from simple and low-cost to more complex actions. Most completed input data should refine the analysis to provide more customized improvement recommendations.

2.2.4 Building IEQ satisfaction

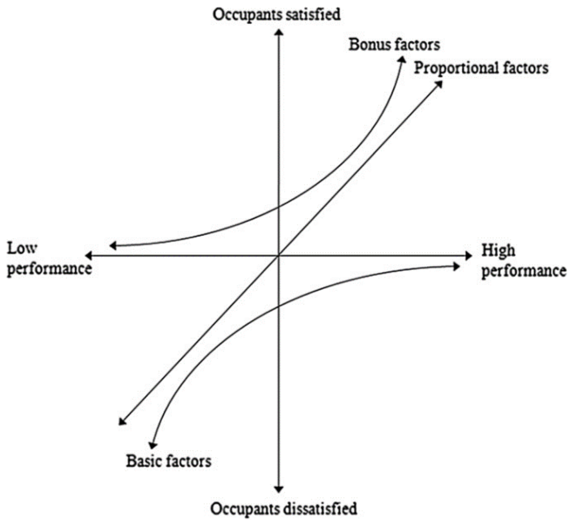
Satisfaction is dictionary-defined as the condition of having a desire or need to be fulfilled. One of the key features of satisfaction research is to understand the needs, identify and prioritize the determinants and optimize the process, since satisfaction reflects the emotion and behavior which can be influenced by different attributes from the product or service (JIN *et al.*, 2021). From theory of attractive quality, developed in 1984 by Kano, Seraku, Takahashi, and Tsuji in the marketing context, different relations between the satisfaction and the degree of fulfilment of a function are explained with various quality attributes. To better visualize the perceptions of either a product, service or design, authors developed the Kano model, which explicates when a quality attribute fulfils the function or fails to function, how it influences satisfaction and what categories the influence can be classified into (JIN *et al.*, 2021).

Table 4 – Quality categories adapted from Kano model to IEQ occupant satisfaction

Categories	Definition
Basic Factors	Minimum requirements: occupants only notice this kind of factor if they are somehow deficient or defective. Don't necessarily enhance overall satisfaction but can cause dissatisfaction when they are not fulfilled.
Bonus Factors	Beyond minimum expectations: when a product performs very well, there is a strong positive effect on occupant's satisfaction. However, poor performance doesn't necessarily result in dissatisfaction.
Proportional Factors	Linear relationship between occupant's satisfaction and the performance of these factors. When they perform well, occupants will be satisfied. And when they perform poorly, occupants will be dissatisfied.

Source: (KIM; DE DEAR, 2012)

Figure 5 - Kano's satisfaction model adapted to IEQ occupant satisfaction



Source: (KIM; DE DEAR, 2012)

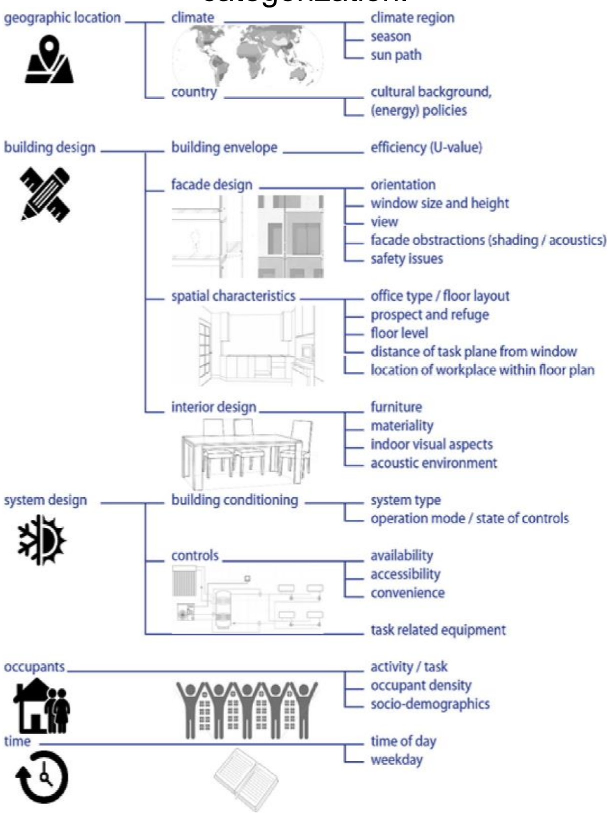
The Kano model can be viewed as an efficient and potential method for IEQ assessment related to satisfaction. Adapting the Kano model to the building context to evaluate occupant satisfaction with IEQ in office buildings, Kim and de Dear (2012) study was based on CBE Occupant Survey (further presented in item 2.2.2.2) database, with 43,021 questionnaires in 351 office buildings. IEQ factors were classified into three quality categories (basic, proportional and bonus factors, as showed in Table 4 and Figure 5) according to the direction of their effect on occupant satisfaction. From their study, evidence showed that under and over performance on IEQ items differ in the strength of impact on occupant satisfaction, signaling nonlinear or asymmetric relationship between overall satisfaction and some of the IEQ factors' performance. In effect the influence of individual IEQ items depends on whether the item in question is delivered at a satisfactory level or not. For instance, authors cite the importance of 'temperature' as ranked 11th out of the 15 factors when thermal conditions are satisfactory but increases up to 7th place when thermal conditions deemed to be unsatisfactory. Since survey respondents (age, gender, type of work, hours spent in the workspace), operation modes (naturally ventilated, air conditioned and mixed-mode), and across various climate zones and countries (Australia, Canada, Finland but mainly in USA) were diverse, results indicate that Kano model generalizes successfully to the IEQ domain and, therefore, it is assumed that outcomes apply to office buildings in general (KIM; DE DEAR, 2012).

2.2.5 Multi-domain IEQ studies

Literature investigations of environmental conditions effects on occupant comfort traditionally isolate IEQ individual parameters in simplified experimental designs rather than considering the complex multi-modal interactions that impact occupants in actual office buildings (PARKINSON; PARKINSON; DE DEAR, 2019). According to Mahdavi *et al.* (2020), the assumption appears to be that, by achieving best performance in all individual domains, results in the optimum building performance overall. Regarding occupant satisfaction, however, skepticism persists due to confounding factors which can potentially distort the relationships between occupant satisfaction and IEQ parameters, showing that increases in occupants' overall satisfaction do not correspond uniformly to improvements of individual IEQ factors (KIM; DE DEAR, 2012).

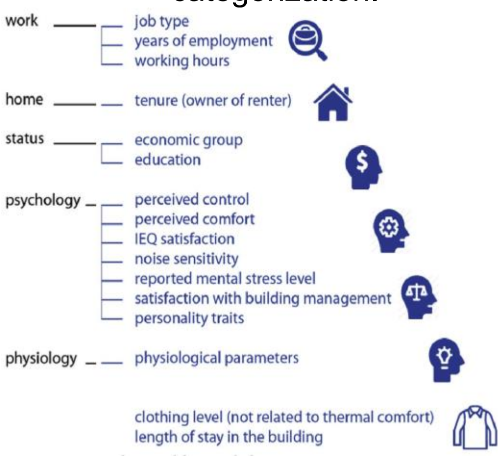
The presumed linearity in relationships between factors on IEQ models and the fragmentation of effects in individual parameters have both been focus of attention recently (MAHDAVI *et al.*, 2020; POLLARD *et al.*, 2021; SCHWEIKER *et al.*, 2020a). From the Environmental Psychology research field, the occupant-building relationship is characterized as total, comprehensive and continuous, raising the importance of perceptual process knowledge (CAVALCANTE; MACIEL, 2008), bearing in mind that the human sensory system receives information regarding multiple indoor environmental exposures. Despite that, the majority of scientific literature considers environmental influence on human perception and behavior in isolation, pointing out that an understanding of multi-domain environmental effects is lacking (SCHWEIKER *et al.*, 2020). There is a general agreement (at least at a theoretical level) that achieving high-performance in built environments requires a deep integration of diverse IEQ domains (MAHDAVI *et al.*, 2020). Complementarily, research drivers should also follow integrated approaches, seeking for patterns of stressors beyond the environmental parameters used in guidelines, from physiological, psychological, personal, social or environmental nature and their integrated effects on user comfort and wellbeing over time (ALTOMONTE *et al.*, 2020).

Figure 6 - Contextual variables and categorization.



Source: (SCHWEIKER *et al.*, 2020a)

Figure 7 - Personal variables and categorization.



Source: (SCHWEIKER *et al.*, 2020a)

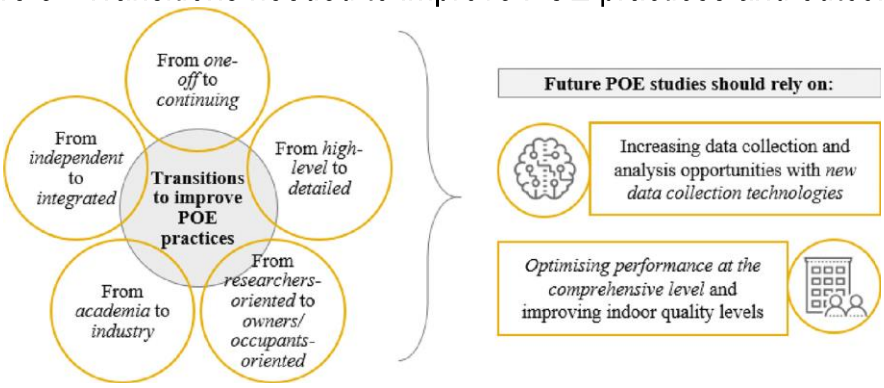
Addressing this knowledge gap, recent research has been seeking a clearer multi-modal scenario. Schweiker *et al.* (2020) reviewed studies applying multi-domain approaches to people's perception of the indoor environment and their resulting behavioral outcomes, revealing the diversity of approaches and findings. A relevant outcome was that many studies assign observed differences in perception or behavioral patterns to the type of building, while neglecting the multitude of other potential influences (e.g., non-documented contextual or personal differences). According to the authors, without addressing, discussing or eliminating potential confounding variables, assigned causalities could be mistaken (SCHWEIKER *et al.*, 2020b). That means, in addition to the four main indoor environmental domains, contextual (Figure 6) and personal variables (Figure 7) influence occupants' perception and behavior and should be addressed. Those shall include a clearer interdisciplinary characterization of what comfort, health and wellbeing implies in terms of design and operation of buildings, the interaction of different factors that may influence its achievement and the development of suitable metrics and tools to sustain and verify it (ALTOMONTE *et al.*, 2020).

Considering comprehension of multi-domain effects has recently been raised as a knowledge gap from literature review, it is inconsistent to propose any building evaluation outcomes without research support. However, the assessment framework tool can contribute back from practice to research field, once building evaluations are draw on physical measurements and laboratory research, but are predominantly about empirical field work, visiting and studying real buildings in use and talking to real people (LEAMAN; STEVENSON; BORDASS, 2010). Therefore, providing the data needed from real world to research field can support consistent investigations from real life experiences.

2.3 INNOVATIONS MOVING IEQ ANALYSIS FORWARD

Considering all the possible drawbacks to BPE presented and widely noted during occupancy phase studies, building research has recently faced new opportunities to gather and analyze data from the built environment, as presented in Figure 8. Innovations on technology for both objective and subjective data collection have improved, providing promising pathways to IEQ analysis, and bringing new chances to achieve more comfortable and healthy workplaces. This section presents selected field studies that explore new methodology on either objective measurement relying on new available technology, and new approaches for subjective data collection from occupants.

Figure 8 - Transitions needed to improve POE practices and outcomes.



Source: (BAVARESCO *et al.*, 2020)

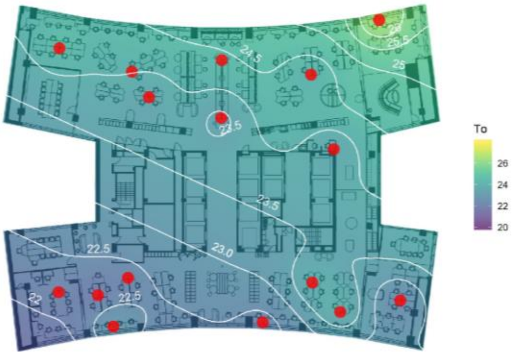
2.3.1 Objective measurements continuous monitoring and data fusion

Pollard *et at.* (2021) study tried to establish the feasibility of synthesizing individuals' continuous IEQ exposure based on high-resolution and real-time location data, with unprecedented level of accuracy and across a long length of time (POLLARD *et al.*, 2021). Pilot study took place on a 1,220 square meter floor from a commercial building in Sydney, Australia, which could accommodate approximately 160 employees in a large open-plan office layout. IEQ parameters were collected from a total of 18 SAMBA sensors spotted across the office floor, bringing an overall density of one SAMBA device per 67.8 square meter. In order to track and locate users in real-time, the LeaseAccelerator Space Optimisation system was used from a Real Time Location System (RTLS) installed at the research site, with an overall density of one sensor per 26 square meters. Each location tag was attached to a participant's access card, required to be always carried for identification and building access.

To estimate IEQ variables at each location on the floor, authors adopted cubic splines, which consist in a form of generalized additive model that fits a smooth surface of IEQ variables across the entire floor plan based on measurements at the IEQ sensor locations and allowing interpolation between them. By merging these estimates with participants' RTLS data, it was possible to estimate environmental quality exposure to each participant at any point in time. The results could then be visualized as maps of individual paths through space from longitudinal measures of exposure to any IEQ parameter and as distributions of exposure levels for each individual participant. Figure

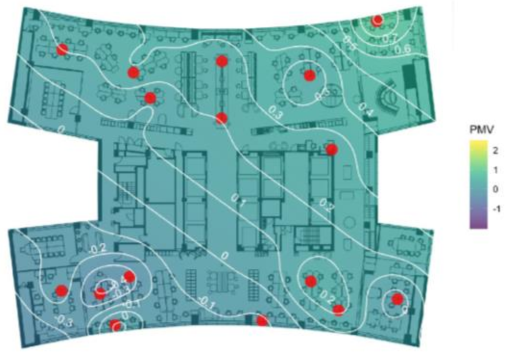
9 presents the outputs from mean operative temperature (To) zones and Figure 10 shows mean PMV zones, both at midday on workdays during research period on office floor, with indication of SAMBA sensors location.

Figure 9 - Mean To zones displayed as contours on office floor.



Red dots indicate SAMBA sensors location.
Source: (POLLARD *et al.*, 2021)

Figure 10 - Mean PMV zones displayed as contours on office floor.



Red dots indicate SAMBA sensors location.
Source: (POLLARD *et al.*, 2021)

Results indicated that synthesis of IEQ and occupant location data could be used to investigate the relationship between IEQ, occupant health and wellbeing by including occupant survey data in the results. Authors mention Ecological Momentary Assessment (EMA), which is presented in section 2.3.3, as a tool for collecting occupant data in real-time, helping to illustrate temporal patterns. The resultant data framework could be used to investigate occupant satisfaction with the indoor environment at a resolution not yet seen in the literature, as well as perceived productivity and other relevant indicators to occupants and organizations (POLLARD *et al.*, 2021). Moreover, by crossing IEQ data together with occupant survey methods might help understanding multi-modal domain exposure, allowing continuous analysis through time and conditions variation, which can help to find correlations between diverse parameters.

Authors also acknowledge that potential benefits of linking location data with participant demographic, health and other personal information to assess research interventions must be carefully considered against the potential for participant harm in future studies (POLLARD *et al.*, 2021). Considering this theme has arisen from a recent technological advance, which is currently a topic under debate, it still needs policies and regulations that guarantee user protection. Risks involved in accessing personal data at this level of resolution are high, and precaution measures must be strictly taken so that collected data can actually serve the purposes of the investigation, which are focused on occupant's health and wellbeing.

2.3.2 GIS tools for data visualization of results

Lee et al. discussion raised awareness that findings and output visualization from POE are often communicated through extensive reports full of technical terms and charts, restricting reach of information among specific professionals. Therefore, consequence is not only the previously mentioned issue of fragmentation of IEQ parameters, but also the inability for nonprofessionals such as building owners and occupants themselves to understand building performance. Since building operation involves constant decision-making, the wider the building evaluation outcomes can go, the better. Even the simplest result presented in an intuitively and readable way can help decision-making processes to be more reliable, cost-efficient and less time consuming.

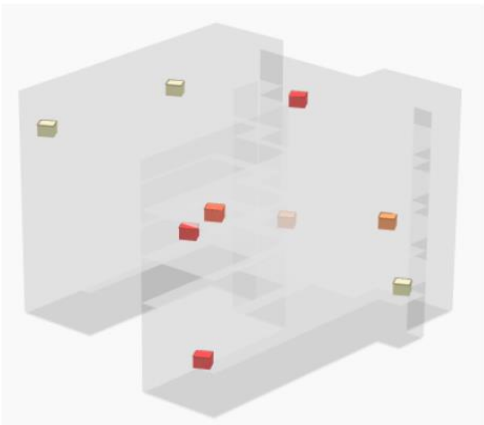
In this regard, Geographic Information System (GIS) tools could be a great solution to visualize occupant feedback and display the spatial analysis of the building on maps, making it easier to link diverse stakeholders, from academia to industry (LEE et al., 2020). Lee et al. study proposed a new occupant survey system in Korea based on GIS tools and open-source spatial information. The difference between the proposed platform and existing online survey systems is that the survey information database was linked to building shapes on the map, providing more intuitive insights for building owners and occupants with three-dimensional data visualization (LEE et al., 2020).

Pilot study tests of the platform were conducted focusing on occupant satisfaction with IEQ factors through seven-point rating scale both web-based and mobile application questionnaires. The five-story selected building had its information regarding number of floors automatically linked from the GIS building-integrated information. Whenever participants accessed the online survey, they should confirm location and shape polygon of the building to be surveyed, first by filling its address and second by choosing their occupied location in the building, inputting 3D spatial information in the shape polygon. After this, the occupant satisfaction survey started, and all information was saved in the database when submitted.

Occupant satisfaction outputs were expressed using small cubic colors for each building floor, as presented in Figure 11, following a color scale to express user satisfaction; and overall building result was expressed by filling its polygon: buildings with high occupant satisfaction are colored closer to green, whereas lower IEQ satisfaction are indicated in red. Figure 12 shows the results from a second pilot study developed in Seoul city, Korea, where all the buildings in the map show the average occupant satisfaction for IEQ factors.

Authors concluded that the platform was able to provide a better understanding from satisfaction survey results and to identify patterns of spatial distributions of occupant satisfaction and dissatisfaction throughout the building. Also, from a long-term perspective, they point out that it is expected that policymakers and planners can compare low and high building performance by comparing neighborhoods and thus the results of the system can be evidence for helping propose regulations on building performance improvement (LEE *et al.*, 2020).

Figure 11 - Three-dimensional spatial visualization on indoor map.



Source: (LEE *et al.*, 2020)

Figure 12 - Three-dimensional spatial visualization on satellite urban map.

Source: (LEE *et al.*, 2020)

This study enlightens an opportunity to connect POE studies with existing GIS technology in order to reduce time and costs associated with similar building evaluation, which still relies on extensive static reports. This kind of outcome representation can also be set up to express whichever indicator one is interested in, by gathering related building information on the same database.

2.3.3 Real-time occupant satisfaction data collection

Regarding occupant surveys, recent literature has brought attention to a shorter, experience-focused survey methodology known as Ecological Momentary Assessment (EMA). Definition of EMA consists of a range of methods using repeated collection of real-time data on subjects' behavior and experience in their natural environments (SHIFFMAN; STONE; HUFFORD, 2008). EMA approaches carry three key features in common. First, information should be collected in real-world environments, as participants go about their lives. Second, assessments are focused on current state, about current or very recent feelings, rather than asking for recall or summary over long periods, aiming to avoid error and bias associated with memory retrospection. And third, assessed moments should be strategically selected, whether based on particular features of interest by random sampling or event-based sampling schemes. In addition, participants must complete multiple assessments over time, providing a picture of how their experiences and behavior varies over time and across situations.

In most cases, participants are asked to complete typical questionnaires either at the beginning or at the end of the EMA period, or both, in addition to asking for the core momentary responses (SHIFFMAN; STONE; HUFFORD, 2008). EMA studies generally have used relatively small numbers of surveys - between four and eight reports each day. Sampling strategies can be divided into two main categories. Time-based sampling consists in recording responses at various times throughout the day, either at predefined intervals (namely "interval-contingent") or at randomly occurring intervals (namely "signal-contingent"). On the other hand, event-based sampling registers occurrence of events of interest throughout the day, namely "event-contingent". Sampling strategies might have different implications and drawbacks on research results. For instance, participants, giving them the opportunity to change their daily experiences to incorporate the scheduled surveys, might anticipate interval-contingent sampling. Signal-contingent survey notification can occur at inopportune times and result in larger amounts of missing data. And event-contingent recording can only work correctly if participants accurately identify the events of interest each time they occur (BEAL; WEISS, 2003). Therefore, those issues should be considered in choosing when to collect EMA data.

Data collection for EMA studies have also evolved over time. For time-based assessment schedules, signaling participants is required, which can be done using an electronic device. Previous studies adopted beepers as a Personal Digital Assistant (PDA) (SHIFFMAN; STONE; HUFFORD, 2008), and nowadays data can be collected through phones or wristwatches applications, named Experience Sampling Program (ESP) (BEAL; WEISS, 2003). Those applications allow researchers to define questions, choose when to send it to participants as well as define how they should be notified to respond. Researchers can also enable participants to view their previous responses to show changes in moods, thoughts or behaviors, if their interest accomplishes diary formats, since data is uniquely linked to each participant.

EMA methods can be used to study a very wide range of behaviors, experiences and conditions, including studies of work activity and satisfaction (SHIFFMAN; STONE; HUFFORD, 2008). According to Beal and Weiss, interest in EMA is stimulated by three factors, all of which are relevant to the study of work behavior:

> First, there is an increasing recognition that important states and behaviors vary meaningfully over time. Second, there is a desire to examine psychological processes in more detail, on a real-time basis, in field settings. This desire is accompanied by the realization that the processes that explain the causes and consequences of variability over time are not well modeled by between-person analyses of subjective aggregations. Third, there is a recognition that when researchers wish to understand the nature of many prior experiences, behaviors and states, respondent attempts to recall and describe such occurrences are too inaccurate to serve as operations of the actual occurrence of these experiences, behaviors and states (BEAL; WEISS, 2003).

Recent studies on building evaluation applied the methodology for different purposes. Jayathissa et al. field study tested the ability of an intensive longitudinal method to capture numerous environmental feedback data by using EMA methodology. Authors studied how high-frequency EMA (time based with signal-contingent sample), conducted through an open-source app developed for smartwatches, combined with sensor data time-series analysis could enable evaluation, control and rethinking of the design of indoor environments (JAYATHISSA *et al.*, 2020). They argue that, by receiving a large amount of feedback from a single person in a diversity of spaces and comfort exposures, would provide the ability to understand one's comfort preference tendencies. Behavioral tendencies could then be used to segment people into groups with similar comfort preferences, increasing the accuracy of predicting where a person will be comfortable without additional sensors.

Pilot test was conducted at the School of Design and Environment from National University of Singapore (SDE/NUS). Thirty participants were recruited, with priority for people who work full-time in SDE buildings on campus, and they were asked to wear a Fitbit Versa smartwatch (FITBIT, [*s. d.*]) during daytime hours while on the NUS campus for a two weeks period. Authors claim that use of a smartwatch for data collection is user-friendly enough not to significantly disrupt any ongoing activity. Comfort preferences were collected through cozie platform (COZIE-APP/COZIE, [*s. d.*]), built on Fitbit smartwatches as presented in Figure 13. Preference votes were chosen as the most applicable feedback due to a three-point scale that is most appropriate for frequent watch-based surveys. Also, they provide meaningful information by indicating how the occupant would want the environment to change, as opposed to satisfaction or sensation survey types that only capture how the occupant feels. Experiment also comprised Wi-Fi-connected IEQ sensors to measure temperature, humidity, noise level and illuminance. To determine occupants' location within the building, 100 Bluetooth beacons were installed throughout the building, which communicated with a smartphone application to determine participant location with one-meter precision. Objective information was merged with the subjective preference feedback data in the cloud.

Figure 13 - The cozie watch-face, built on Fitbit smartwatch.

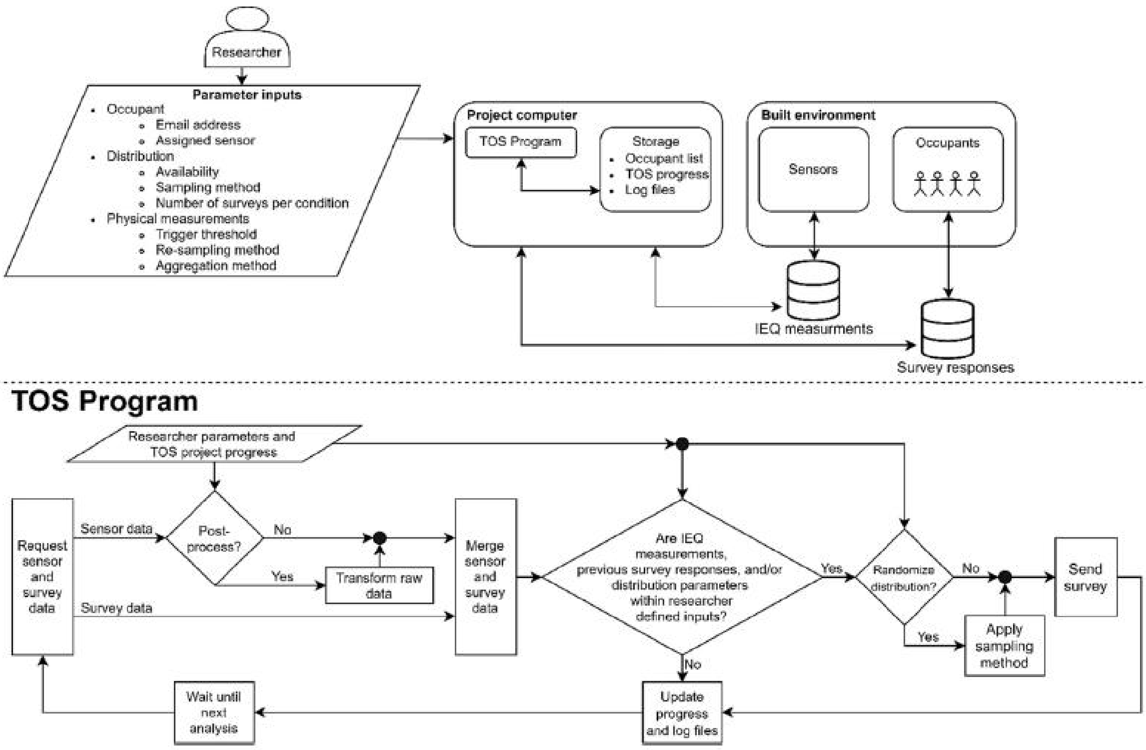
Cozie platform was used to collect subjective feedback. The phone that is paired with the Fitbit can be used to set up additional questions. Source: (JAYATHISSA *et al.*, 2020)

Results showed the effectiveness on deployment and implementation of collecting intensive longitudinal feedback from occupants in the built environment and that utilization of high-frequency subjective data has potential for building evaluation and occupant comfort optimization. Time series comfort profiles could also serve as input data for occupant-centric-control efforts of building systems, which can then optimize for human comfort and energy optimization, changing the paradigm in which facility managers operate a building (JAYATHISSA *et al.*, 2020). Due to high sampling rate, periods of discomfort can be mapped to particular times and/or specific groups of people. This outcome goes towards the need raised by Graham et al. to include classifying occupant characteristics such as age, gender, ethnicity, education and other experiences relevant to target variables to better contextualize the survey results and respondents (GRAHAM; PARKINSON; SCHIAVON, 2021).

Testing group-based models from this study was essential to test the ability to cluster occupants such that it was not necessary for everyone in an office to wear a smartwatch. In practical terms, however, building owners and organizations must not expect all occupants to be willing to use devices, and those who agree might likely have a limited amount of patience for giving feedback over long periods. In that sense, Duarte Roa et al. developed an online platform that incorporates storage and retrieval of completed occupant responses along with specific environmental conditions from the moment survey was completed, and distribution of occupant surveys at specific environmental conditions or throughout the researcher-defined region of interest (DUARTE ROA; SCHIAVON; PARKINSON, 2020). Those characteristics meet EMA event-based sampling, with the key advantage of enabling researchers to define specific conditions to trigger survey requests and increasing probability of responses to contribute to answering their research questions. In order to identify interest conditions, the study also required continuous real-time IEQ measurements together with a tracking system for distribution details, target conditions and recording when surveys were sent and completed.

Targeted Occupant Survey (TOS) platform have three key parameter sets to define when and whom to send the occupant survey: a) occupant list, containing relevant participant information such as email addresses, personalized survey links and identification number of the assigned IEQ sensor; b) survey distribution, which controls when occupant survey requests should be sent to participants; and c) physical measurements, which controls any transformations performed on sensor data and it can be defined to trigger survey requests. Sampling method for survey distribution could be defined by time of day or day of week, number of survey requests or participant responses. Another key input is the maximum allotted surveys per participant per target IEQ bin, which stops sending additional survey requests to a participant when the maximum number of surveys for that condition has been met. The platform was tested in a pilot study conducted in David Brower Center (DBC) office building in Berkeley, California, with eight recruited occupants. Figure 14 illustrates an overview of TOS workflow.

Figure 14 - Targeted occupant survey (TOS) platform overview.



The top schematic shows a high-level overview of how TOS projects are setup while the bottom schematic shows the TOS program flow. Source: (DUARTE ROA; SCHIAVON; PARKINSON, 2020)

Results showed that flexibility of TOS parameters offer a significant advantage for field studies of occupant satisfaction by minimizing redundancy in the collected data. In addition, the platform allows to keep the records of when and at what target IEQ measurements the building occupants have completed the surveys, which can also help to track and understand users perception of built environment over time (DUARTE ROA; SCHIAVON; PARKINSON, 2020).

2.4 FUTURE OF SPACES FOR WORKING

Until recently, design of office buildings followed a 19th century model of work, where workers were brought together in space and time to a standardized and often uniform workplace so they can have access to necessary job tools. Employees were mainly asked to physically perform rather than thinking, and to gather workers together was also a requirement for job supervision (VISCHER, 2008). From changes in the 21st century world, led by service and knowledge driven economy, mainly in the tertiary sector, few of those conditions are still valid. Transitions from material to human capital, which relies on people's ability to think and produce new knowledge, have made work dynamics radically change, supported by technological advances in computers and communications. Regarding physical environment, office workplaces transitioned to become more diverse, by inviting people to make a social life at work but also by encouraging employees to work at all hours.

Recently, COVID-19 pandemic pushed employers and employees to adapt through a massive workplace migration derived from imposed safety restrictions, moving from the office to Mandatory Work from Home (MWFH). After more than two years of working remotely, a new transition movement is being raised by the struggle of bringing knowledge workers back to the office. As it become clearer that people no longer strictly need to be fixed in space and time to work together, prior attempts to impose an in-office presence has led to record low retention rates and deteriorated employees experience at work, from ability to focus, stress levels, and level of satisfaction at work, creating a liability for employers (VOX MEDIA, 2022). Also, nearly 80% of employees working remotely see themselves as being just as or more productive than they were before the pandemic, while less than half of leaders agree (WORKLAB MICROSOFT, 2022). Such figures show employers and employees are demonstrating different understandings about what the office is for.

Beyond corporate cultural aspects, the workplace itself is also transitioning. After several months of imposed social distancing, indication showed that people do need a shared space to meet and work together. The loss of social connections is likely to negatively impact workers, since high-quality social interaction, including handshakes and informal chats among coworkers, are essential for mental and physical health (KNIFFIN *et al.*, 2021). Whether leaders must establish the why and when employees must attend to the office, they must also rethink how space can play a supporting role (VOX MEDIA, 2022). It is clear that the diversity of work arrangements will need to be studied, regarding how it affects creativity, innovation, and engagement rates, given the likelihood of hybrid work to be a great trend of most companies around the world. Any attempt of prediction cannot be less speculative than accurate regarding the future of work and, consequently, the future of workspaces. From the entire struggle, the pandemic may offer a rare opportunity to rethink the workplace and find smarter, safer, and more comfortable ways of working together.

Beyond that, quality of indoor environments is in line with the United Nations Sustainable Development Goals, especially Goal 3 "*Good health and well-being*" and Goal 8 "*Decent work and economic growth*". Employees' needs and preferences should be put at the center of building design, technology and service in terms of motivating and lifting their satisfaction to the environmental quality indoors (JIN *et al.*, 2021). Any process of environmental intervention must consider the importance of users' perspective, and can be based on how well or not they support occupants' work and thereby affect the productivity of the organization (VISCHER, 2008). Therefore, it is preferable for employers and decision-makers to use research evidence to consider environmental quality decisions as investments, bearing in mind workspace can and should be a tool for performing work.

2.5 FINAL DISCUSSION AND CONSIDERATIONS

From the presented literature review, it becomes clear that IEQ performance evaluation stands as an asset for building operation phase, keeping in mind that spaces matter to the extent to which they support the occupants within. Thus, it is essential to address users expectations and needs from their environment (GRAHAM; PARKINSON; SCHIAVON, 2021). In addition, results from occupancy phase of BPE studies are not always published and widely disseminated. It might be exclusively available to the architect, client, or stakeholder who commissioned the study. However, findings focusing on the experiences of building users are often relevant to a broad range of building design and management decisions (PREISER; VISCHER, 2006). It is important for them to know how different IEQ factors influence occupant satisfaction before rational priorities can be set, particularly when resources are constrained (KIM; DE DEAR, 2012).

As presented, advances in building science, digital survey methods and the understanding of psychology of occupant perception of IEQ can now offer a new framework for occupancy phase of BPE. On one side, the promised ease of continuous monitoring of environmental parameters provided by technological innovations might overcome spatial and temporal sampling problems to properly capture buildings IEQ variability. On the other hand, digital survey methods with instantaneous approaches can help to understand occupant's perception, behavior and satisfaction variations with their work environments accordingly, reducing by a fair amount the bias risk of relying on existing recall methods and providing a clearer picture of how spaces are actually used. But mainly, the possibility to combine both sides might also enlighten a new path for a mixed-method approach and provide the knowledge basis of the occupant-building relationship. It can also help to provide information regarding multi-domain experiences in real-life contexts, which might contribute back to the research field of building science. Therefore, it is believed that efforts towards IEQ evaluation must embrace those advances, trying to consolidate this combination.

2.5.1 User Satisfaction Assessment Framework: why, for what and for whom

A tool for evaluating user satisfaction with built indoor environmental quality can range from practical information based on the entry of basic variables, as in the example presented in 2.2.3.2, to a governmental certification with validation by a third party, such as item 2.2.3.1. While the first has a simpler and direct approach, with guidelines specifically aimed at building operators, the second has a public policy making bias aiming at national-level building benchmarking. Despite the structural differences between the two of them, both seek to improve performance regarding environmental quality, meaning it must embrace different building operation scales and stakeholders in order to reach a better delivery for their occupants. This research seeks to design an occupancy phase BPE framework in which mentioned aspects are taken in a practical way and aligned with real-life in current buildings. This formal characterization should offer the support needed from literature review, contemplating the outlined potential strengths and possible paths for BPE studies. From both Environmental Psychology and Occupant Behavior field studies, it was possible to reach numerous methods of collecting occupant-related data for researching building occupants, each with its own strengths and weaknesses.

Regarding subjective variables from occupants, surveys over 20-years of experience and a vast database could simply be translated for application, assisting any research data analysis process. However, it is assumed that reviewing and comparing the existing occupant survey tools can be of greater value than importing it, looking to clear any critical issues and properly adjusting them to local context. In addition, it is intended to complement this type of instrument, looking for different user survey tools in order to provide meaningful and complete outcomes. Considering that our perception and experience of the built environment from a multi-modal perspective in user satisfaction is still being studied, data obtained with this type of tool could contribute to extracting information from real life experience to support further studies. Another important point concerns the future of post-pandemic offices and workplaces. How changes in safety and occupancy protocols will affect satisfaction, engagement rates and productivity are still unknown. Therefore, it is presumed that an assessment tool that intrinsically considers user perception and satisfaction in the assessment of work environments can help lead to a better understanding of possible problems and their improvement.

2.5.2 Main guidelines for Assessment Framework development

Complementary to the highlights raised by the literature review, there are four main points which must be faced as guidelines to be pursued within the proposed BPE framework. First, concerns dynamic data integration. Framework evaluation should consider how its occupants combining real-time approach assessments, including continuous unobtrusive environmental measures with right-in-time occupant feedback as subjective variables. This approach should enable understanding of how occupant behavior and experience may vary over time and across changing contexts. Second is communication. Data processing and analysis from objective and subjective variables should generate global and specific key indicators related to users' satisfaction in ways to identify eventual dissatisfaction promoters. Performance indicators must allow benchmarking of diverse building aspects over time, providing a tool with clear information that shall reflect research, policymaking, and owner-occupant-oriented perspectives. Third main guideline is usability. The framework tool interface should consider user experience interaction since data inputs until reporting results. That means that the assessment interface should be created to deliver findings in an accessible and easy-to-understand manner to a multidisciplinary group of building stakeholders, including occupants. Finally, flexibility. Long term adaptation to particular and/or specific needs is a must have. That means the framework implementation should foresee a combination of aggregated "modules", allowing building management and operation to adjust to requirements for better evaluation and also reflecting its own development over time. To be able to conduct replicable and repeated occupant surveys overtime in the same building means the three first points need to be achieved, otherwise no adherence would be reached.

3 DEVELOPMENT OF THE ASSESSMENT FRAMEWORK

The proposed assessment framework focuses on occupancy phase of BPE. It is a process-oriented convergent modular research design performed in parallel series to be compared and interpreted together, with each module feedforwarding the next one, and extending throughout building occupancy. Mixed-method approach must combine quantitative and qualitative data, aiming at triangulation purposes to drive conclusive analysis. Quantitative method is supported by building measurements, which consist in monitoring IEQ variables of occupied workplace environments, acquired passively through sensors. Qualitative method is supported by survey tools, both through interviews and questionnaires which rely on reporting occupant satisfaction.

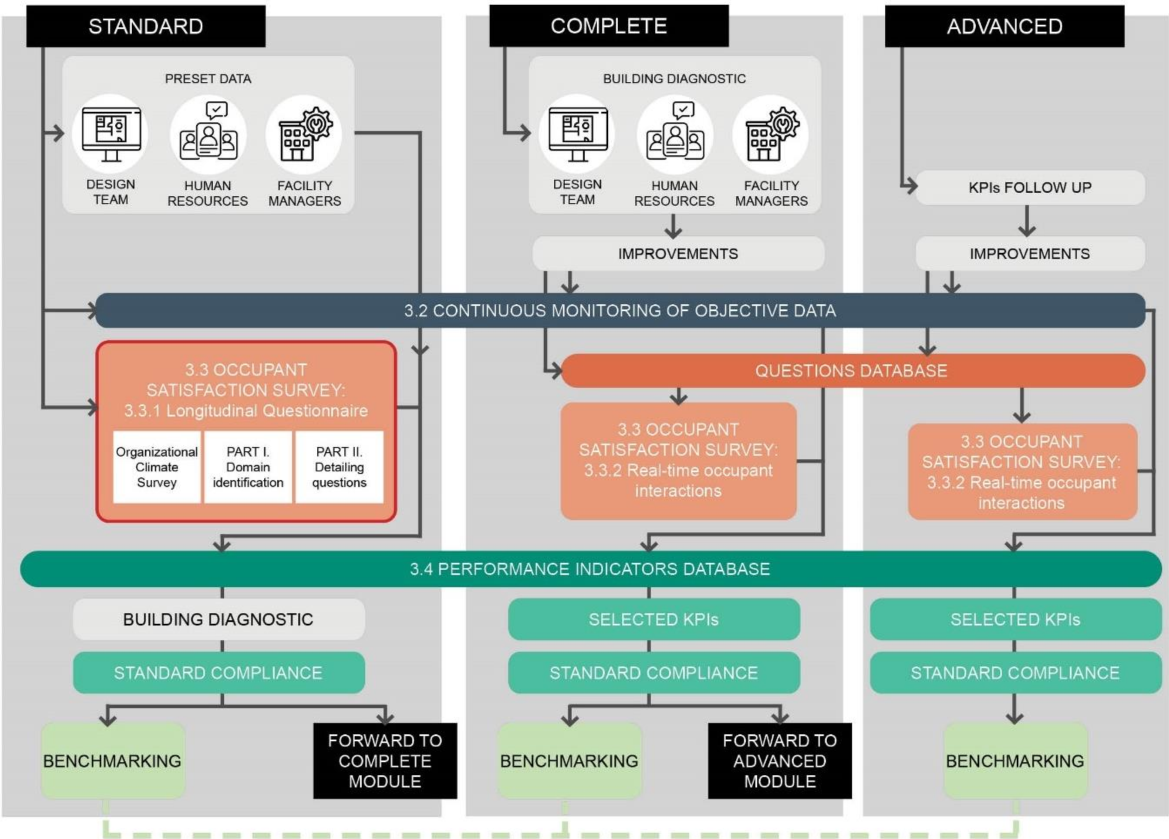
It is worth stating that the whole assessment framework was proposed; however, only the longitudinal questionnaire (item 3.3.1, highlighted in red in Figure 15), was profoundly developed and submitted to tests (further presented in chapter 4). The other protocols and instruments proposed, both for physical and subjective variables, should be object of study in future research.

Organization of this chapter is taken as follows: section 3.1 introduces the proposed framework assessment by presenting the designed modular combination for long-term adaptation. The two following sections consist of detailing building data to be collected and how. First, the required objective continuous monitoring data is presented in section 3.2. Second, the proposed methodology for gathering occupant subjective information is presented in section 3.3. Definition of required data to be collected must also be able to give the outcomes needed for adequate performance indicators, which are discussed in section 3.4.

3.1 ASSESSMENT FRAMEWORK MODULES

The proposed assessment framework consists of three main modules (*Standard, Complete* and *Advanced*), as illustrated in Figure 15. It aims on provide a better understanding of building specific particularities and support decision-making process by helping to identify possible recommendations for IEQ and user satisfaction enhancement. Therefore, the proposition of a modular-type structure is intended to create a clear and gradual process of data collection for problem identification, implementation of necessary corrective actions, and further follow up for reevaluation. This continuous evaluation process aligns with BPE model, and not only allows long-term adaptation for building owners and managers but, mainly, suggests also continuous improvement of user satisfaction over buildings' occupancy phase.

Figure 15 - Assessment framework modules.



Next items present each module contents and indicators proposition.

3.1.1 Standard: diagnosing the building

From assessment implementation, *Standard* module is triggered. This first module is intended to explore and picture the status of building IEQ. Therefore, tools and methods proposed for gathering data should take extensive and in-depth investigations, aiming to provide a solid building diagnostic. Starting the data collection process is the *Preset Data*, which constitutes the basic information regarding the assessed building. *Preset Data* should be obtained both from previous phase of the BPE, that is, design and construction teams, as well as from Facility Managers and

Human Resources. The list of required data is presented in Table 5, which addresses most of contextual variables (SCHWEIKER *et al.*, 2020b), aiming to provide a clearer interdisciplinary building and occupancy characterization. Interviews with Facility Managers and Human Resources teams are suggested as a complement to *Preset Data*, individually or in focus groups, since it allows participants to openly explain their opinions and collect stories. These stories from key actors in building operations are expected to be more easily remembered in the future when compared to numbers (DAY; O'BRIEN, 2017). This should also enhance triangulation purposes of mixed-method approach, by helping to delineate the general rules and guidelines defined by these groups and which might influence user occupancy and perception, providing a new layer of information for conclusive analysis. Development of this instrument is object of future research studies.

Table 5 – *Preset Data* required information items and source.

General topic	**Subject**	**Item**	**Source**
Geographic location	Climate	Climate region	
		Season	
	Country	Cultural background	Human Resources
		Energy / labor policies	Human Resources
Building design	Building envelope	Efficiency (U-values)	Design team
	Façade design	Orientation	Design team
		Window size and heights	Design team
		Views	Design team
		Shadings	Design team
		Safety issues	Facility Managers
	Spatial characteristics	Floor plan / office layouts	Design team
		Floor level	Design team
		Distance from windows	Design team
	Interior design	Furniture	Design team
		Internal finishing	Design team
		Visual aspects	Design team
System design	HVAC	System type	Facility Managers
		Operation modes	Facility Managers
	Lighting		Facility Managers
	Controls	Availability	Facility Managers
		Accessibility	Facility Managers
Occupants	Spatial distribution	Activities	Human Resources
		Density	Human Resources
	Sociodemographic	Age	Human Resources
		Gender	Human Resources
		Education	Human Resources
	Work	Job type / income	Human Resources
		Years of employment	Human Resources
		Working hours	Human Resources
		Insurance / benefits	Human Resources

Source: (SCHWEIKER *et al.*, 2020b) adapted by the author

Once *Preset Data* is available, physical building data collection requires implementation of continuous IEQ monitoring systems (detailed in section 3.2), which should provide objective measurements through the whole assessment process for occupied building areas. Regarding subjective data, it means application of a survey capable to provide detailed information on occupant satisfaction (section 3.3.1). This instrument was developed within this research and is further presented in chapter 4. By now, it is worth stating two points: a) the main structure of the questionnaire was divided into two hierarchical parts: the first consists of the minimum mandatory questions that all participants are required to answer, while the latter gathers the respective in-depth questions to each IEQ domain (see item 4.1.4); and b) it was considered that indication of satisfaction and/or comfort with any IEQ domain in part I would dismiss the need to deepen the diagnosis on that subject, focusing only on discomfort-causing issues (see item 4.1.5). In practice, part I works as a filter for the detailing questions in part II, since whenever discomfort is detected, part II is triggered to collect more information. This core-filter structure works itself as a satisfaction performance indicator if no frequent discomfort is to be considered. However, if the detailing questions are triggered to any IEQ domain, part II set of answers should offer a complete picture of satisfaction and comfort to be combined and crossed with *Preset Data* and continuous IEQ monitoring.

Performance indicators for *Standard* module (see section 3.4) are restricted to compliance with applicable IEQ codes and standards, considering that compliance with regulations is the minimal performance and a priority which every building must achieve. When or whether compliance as well as high satisfaction scores could not be reached, this module should bring up recommendations of improvements to be implemented by building managers and operators and should be reassessed on the next module. Indicators are also used for benchmarking with other similar typology buildings. It is also suggested that Basic IEQ Parameters as indicated by Kim and de Dear (2012) should be followed from occupant surveys application.

3.1.2 Complete: following achievements

Second module, or *Complete*, starts after implementation of suggested adjustments for performance improvement on the previous module, if needed. Thus, another round of subjective data collection should be taken, now focusing mainly on real-time interactions with occupants (section 3.3.2). This module is intended to dive deeper on data analysis gathered in the *Standard* module, searching for cause-effects parameters, and helping to identify strengths and weaknesses in both building operation and personnel management. This is the stage where different stakeholders and specialists must be carefully involved, contributing to identify improvements' costs and benefits under different and complementary perspectives. Therefore, *Complete* module analysis must embrace a wider range of variables, crossing building operation data with personnel and health insurance costs, for instance. As much as on the *Standard* module, each indicator must be followed by a clear indication of where critical aspects are, and whenever possible, recommendations in order to guide required improvements.

When evaluating building performance, too few indicators may lead people in the wrong direction, while too many indicators may bring confusion (LEAMAN; STEVENSON; BORDASS, 2010), justifying the importance of selecting the right subset of indicators for specific purposes. Proposition for *Complete* module assessment consists of selecting the appropriate indicators from a predefined set of indices, according to the main operational goals. Proportional IEQ Parameters, as indicated by Kim and de Dear (2012), must be checked from occupant surveys application. Indicators for this module are presented in section 3.4. For benchmarking, standard compliance from the *Complete* module can be compared not only to other buildings with similar typology, but also to the building itself, expressing any achieved enhancements from to *Standard* module results.

3.1.3 Advanced: keeping it high

Third module, or *Advanced*, considers that a desired balance is achieved from operation strategies and other improvements suggested on previous modules, successfully enhancing IEQ performance and user satisfaction. Therefore, this stage consists of monitoring building status regularly, to keep track of indicators accordingly. For that, continuous monitoring of building objective measurements follows operational practices and keeps in touch with users' perception by applying fewer random instant satisfaction surveys. This is the moment when benchmarking results become dynamic, allowing comparison of building itself data over time.

Next section focuses on the tools and needs required for data collection to be used on each stage: continuous IEQ monitoring systems for objective measurements and occupant satisfaction surveys for subjective variables.

3.2 CONTINUOUS MONITORING OF OBJECTIVE DATA

As previously discussed in item 2.2.1, although recent technological advances with great potential to allow the wide adoption of continuous monitoring sensors, this is still a research field that demands further development for implementation - from sensors' costs *versus* accuracy and calibration, until basic guidance on sampling procedures or measurement protocols to ensure reliable representation of physical IEQ parameters. Since existing building standards and guidelines were not developed for technologies that enable continuous measurement, it is necessary to acknowledge that there is no standardized definition that is universally accepted for such measurements. Therefore, the proposition of the objective monitoring protocol within the framework is yet experimental and must be submitted to trial in further pilot studies to be tested, helping to identify any critical points and necessary adjustments and, thus, contribute back to research field. It should be noted that the main interest of just-in-time measurements of the environmental variables is to follow the change of those variables over time, in parallel with occupant satisfaction, for triangulation purposes.

3.2.1 Measurement protocol: required IEQ variables

The IEQ variables measurement are presented in Table 6 and consist of the basic comfort parameters (thermal, IAQ, visual and acoustic) found in the literature. These measurements should be able to provide the proposed indicators for the *Standard* framework module, which consists of verifying compliance with the respective building standards. In addition to monitoring these environmental variables, it is also recommended to follow the occupancy count of each office room, either through access cards, system login or similar. Measurements must be recorded at least once every minute.

After performing the diagnosis and verifying regulatory compliance on the *Standard* module, continuous monitoring must be maintained for the next assessment modules, *Complete* and *Advanced*. This monitoring will be used to guide real-time interactions with users, on an event-based or time-based frequency, according to the oscillations observed in the physical variables over time.

Table 6 - Required IEQ variables, achievable indicators, and standard reference.

IEQ Parameter	Achievable indicators	Standard Reference
Air temperature	PMV / PPD;	ANSI/ASHRAE Standard 55 (ASHRAE, 2020)
Relative humidity	Average PPD;	
Globe temperature	EH [PMV];	
Air speed	EH [Adaptive model]	
Sound pressure level (SPL)	Overall Sound Level; Time-averaged SPL	NBR 10152 (ABNT, 2020)
Illuminance	Work plane Illuminance	NBR ISO/CIE 8995 (ABNT, 2013)
Carbon dioxide (CO_2)	CO_2 * Occupant Hour	ANSI/ASHRAE Standard 62.1
Carbon monoxide (CO)	CO levels	(WHO, 2010)
Formaldehyde (HCHO)	HCHO levels	
Total volatile organic compounds (TVOC)	TVOCs * Occupant Hour	EPA TO-17

Source: (PARKINSON; PARKINSON; DE DEAR, 2019) adapted by the author

3.2.2 Measurement protocol: zone definition and sensor positioning

Measurements must be conducted at diverse locations across office space, and sampling points must be representative of typically occupied workstation areas within each office zone. For zone definition, characteristics of the work environment that might influence users' perception of indoor environmental conditions must be evaluated. For instance, private rooms configure different zones of open-plan workspaces. In turn, open-plan office layouts without partitions between the workstations should have a different zone from workstations with high partitions. Such workplace characteristics were also selected to define clustering of results and are required as sample definition on occupant surveys (further presented on item 3.3.1) for comparative purposes. Spaces reserved for other work activities, such as meeting rooms, noise and/or quiet areas, etc. must be treated as different zones from typically occupied workstations.

Table 7 - Minimal sampling points for device location per office zone.

Layout		1 device to whichever is higher		
		Occupancy	Area	System
Open plan	No partitions	10 occupants	80 m²	air conditioning zone
	Low partitions	10 occupants	80 m²	
	High partitions	5 occupants	50 m²	
Private room	Single occupancy	1 device		
	Shared occupancy	1 device	50 m²	
Other activities: meeting rooms, quiet areas, etc		1 device	50 m²	

Among the same zone, there are three different criteria of sampling points for sensor location: occupancy, area and air-conditioning system availability, and are presented in Table 7. Such criteria were based on Pollard (2021), which adopted a density of one device per 67.8 m²; and Parkinson, Parkinson and de Dear (2019a) recommendation of five devices per floor, or one per air conditioning zone, whichever is higher. Therefore, for definition of minimal sampling points it is required to evaluate the three indicated criteria according to each office zone and select the one with the highest number of devices. For instance, an 85 m² open-plan office zone without partitions and 50 occupants should adopt five sampling points; meanwhile the same zone area with high partitions should adopt ten sampling points.

Each device position within the zone should include interior space and proximity to facades with different orientations at least 1 meter away from walls, doors, windows, direct sunlight, air supply and/or exhaust outlets, mechanical fans, heaters, or other significant source of heat and or cold. It is acknowledged that standard protocols for thermal, IAQ, visual and acoustic comfort conditions recommend its respective variables to be measured on different heights amongst each other. Air temperature and air speed levels, for instance, must be measured on 0.6 m height above floor for seated occupants (ASHRAE, 2020). It is suggested, however, each sensor to be placed preferably (or as near as possible) of the workstation surface, either sitting (0.7 to 0.8 meter above floor height) or standing (1.0 to 1.1 meter above floor height) desks.

3.3 OCCUPANT SATISFACTION SURVEY TOOL

Survey questionnaires are the most common and applied method to gather occupant information. It is defined as a set of questions on a particular topic that does not test participant’s ability, but measures their opinion, interests, personality aspects and biographical information (GÜNTER, 2008). In general, questions should be simple, clear and easily understandable to participants, avoiding technical jargon. To ensure a survey instrument is delivering reliable and valid data, it is important to consider that it should be based on well-defined variables and measurements, that is, scales (WAGNER; BRIEN, 2018). Whenever personal data is collected by interacting or intervening with an individual or their confidential information, this individual is known as a “participant”. Therefore, future mention of occupants in this section is referred to as so.

3.3.1 Longitudinal Questionnaire

Elaboration of this survey instrument is part of this research scope and is further presented in chapter 4. As this survey incites reflection and/or awareness among participants about IEQ at their workplace and its relationship with their own satisfaction, the proposed questions aim to achieve outcomes able to identify critical points, drive possible improvements and, therefore, get back into participants' daily lives. According to ASHRAE (2010), a 40% response rate to a general survey of all occupants is considered sufficient to evaluate the occupancy satisfaction in a building with substantial occupancy. Population size for the *Standard* module should target all building and/or office occupants, aiming to reach high sample sizes, bearing in mind that for diagnostic purposes, the broader the picture, the better.

3.3.2 Real-time occupant interactions

Development of this occupant survey instrument is object of future research studies. This section presents general guidelines for the tool elaboration considering the assessment context of the proposed framework. From literature review presented on item 2.3.3, recent studies have adopted real-time occupant satisfaction data collection based on EMA methodology. Such survey instruments also known as "right-here-right-now" questionnaires require participants to respond according to their right-in-time perceptions or behaviors. These should dictate the development of real-time interactions with occupants to attend *Complete* and *Advanced* modules, concerning time intervals, selecting samples and event-based surveys.

For instrument elaboration, it is suggested to develop a question database regarding topics linked to the longitudinal questionnaire survey for following any critical issue identified from *Standard* module' diagnostic. For instance, whether any kind of dissatisfaction is identified regarding thermal comfort from *Standard* module diagnostic, corrective actions should be taken following recommendations for improvement. The results of this implementation are followed by instant interactions, where mostly preference votes of thermal conditions should be selected from questions' database and triggered for survey. Any complementary topic can also be selected from questions' database, following operational interests. Group questions from the *Standard* module should also drive questions' database sampling. It is expected that group division should facilitate topics organization and sorting of applicable themes to be further investigated. Also, questions regarding participants' status are required for complementary sample characterization. For instance, actual clothing insulation level regarding the number and type of clothes a participant is wearing at the survey moment, windows and curtains status regarding open and/or closed, on and/or off air-conditioning status and so on. As much as the longitudinal questionnaire, population size is linked to office occupancy, and sample definition for this survey can be stratified according to previous outcomes. For instance, following previous example from thermal dissatisfaction outcomes in a given room, sample definition should focus on this population, in parallel with a control group to be defined accordingly.

Regarding survey items and measurement, it is assumed that preference votes are the most adequate feedback for instant occupant interactions regarding the internal environment variables, since it can be easily understood and shortly assessed by users into their daily lives. Satisfaction and sensation votes can also be applicable whenever related to subjects assessed, since they help capture how the occupant feels. All questions must be measured through a three-point Likert scale, in order to keep it as simple as possible and give meaningful outcomes, indicating how occupants would or would not like the environment to change. BOSSA Snapshot satisfaction survey (see item 2.2.2.3) and similar questionnaires identified in literature review must be used as reference for questions analysis.

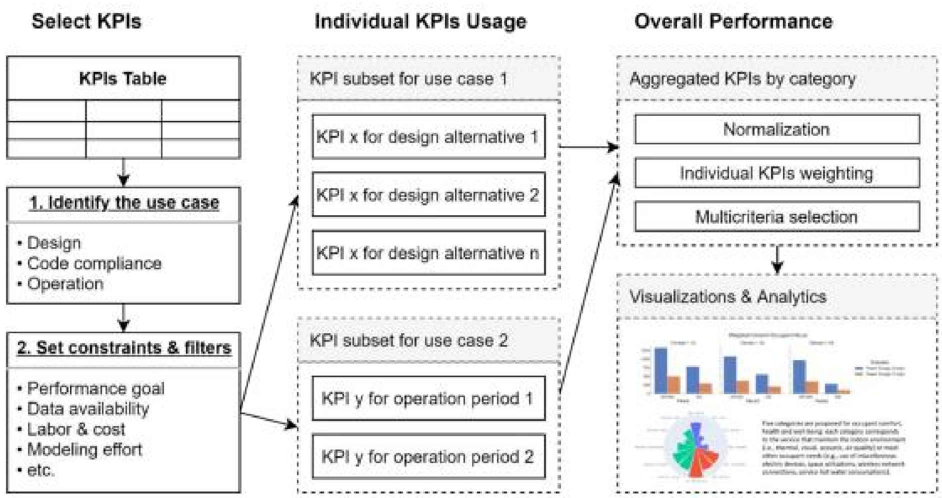
Experience Sampling Program (ESP) applications are the recommended tools for this kind of survey (see section 2.3.3), which would allow question definition as well as when to send and how participants should be notified to respond, aligning with methodology of EMA. Such apps (e.g.: *Expiwell* (EXPIWELL, [*s. d.*]); *movisensXS* (MOVISENSXS, [*s. d.*]); *PIEL Survey* (PIEL SURVEY, [*s. d.*]) were specifically developed in order to help researchers to easily input questions and define target samples, as well as whether it should be event or time-based experiences, and how users should be notified. They also have a simple and friendly user interface for participants, who should take actions for surveys after receiving the notification, beyond providing helpful graphs for the survey outcomes. Ideally, the same survey tool could host both occupant survey instruments, gathering all survey data together.

3.4 PERFORMANCE INDICATORS DATABASE

Indicators are defined as combined values that reflect the performance with easy-to-understand information rather than raw operational measurements (LI; WANG; HONG, 2021). Good Key Performance Indicators (KPIs) must not only measure performance, but must also be objective and actionable, helping managers to measure what matters the most. Also, they must allow benchmarking of relevant building aspects over time, providing a tool with clear information that shall reflect research, policymaking, and owner-occupant-oriented perspectives. As discussed previously in section 2.2.5, performance indicators on building IEQ evaluation often are integrated into IEQ models or indices, based on building standards and certification schemes. Moreover, although there are defined metrics for evaluation, there is no clear methodology for correlating those metrics with occupants' subjective responses. The proposal for this assessment framework is to create a KPI database so that indicators can be chosen according to specific operational purposes, raised from *Standard* module' diagnostic.

To build this database of indicators, it is recommended to maintain reference standards as performance indicators. Such indicators may result in a "fragmented" analysis of IEQ parameters, as discussed previously. However, the traditional path between research and practice has been through the implementation of building codes and regulatory standards. Therefore, they must be kept as minimum parameters, which any building should accomplish. These are the KPIs proposed for the *Standard* module evaluation, as presented in item 3.1. For *Complete* and *Advanced* modules, however, a wide range of indicators beyond building standards might be suitable and help to provide an in-depth assessment of the workplace. It is suggested to adopt parameters identified in the literature review, such as Li et al. (2021) findings from occupant-centric design research. Authors summarized key features of relevant KPIs comprising visual, thermal, acoustic and indoor air quality domains, and reviewed the existing occupant-related metrics, with the aim of identifying limitations and opportunities of improvements (LI; WANG; HONG, 2021). For this research, the original metrics identified on the study were selected considering two criteria: indicators from in situ measurements which could be provided through the variables indicated on Table 6; and with applicability in operation phase, since this framework is oriented to in use office buildings. In addition, it is expected to find threshold references of performance in building evaluation schemes, such as the aforementioned WELL (IWBI, 2020) and Fitwel (FITWEL, 2021), which are specifically aimed at promoting the health and wellbeing, in order to obtain parameters that focus on occupant satisfaction.

Figure 16 - Workflow to choose and calculate selected KPIs.



Source: (LI; WANG; HONG, 2021)

For selection of applicable KPIs, a multiple criteria selection analysis must choose strategies that maximize the overall performance, according to critical issues raised on diagnostic stage and complementary performance goals. Also, for overall performance quantification, it is necessary to normalize and weight each individual KPIs to a consistent scale (e.g., a zero to ten range). Normalization factors for the selected KPIs from Li *et al.* (2021) are presented in ANNEX A – Reference occupant-centric performance indicators. The workflow to choose and calculate the KPIs from the database that might be used to compare overall performance is presented in Figure 16, as suggested by the same authors.

4 DEVELOPMENT OF LONGITUDINAL OCCUPANT SURVEY INSTRUMENT

In this chapter is presented the method for developing the longitudinal occupant survey instrument to be applied in the *Standard* module of the proposed framework. In section 4.1 the development process of the instrument itself is presented, while validation tests and results of pilot study are presented in section 4.2.

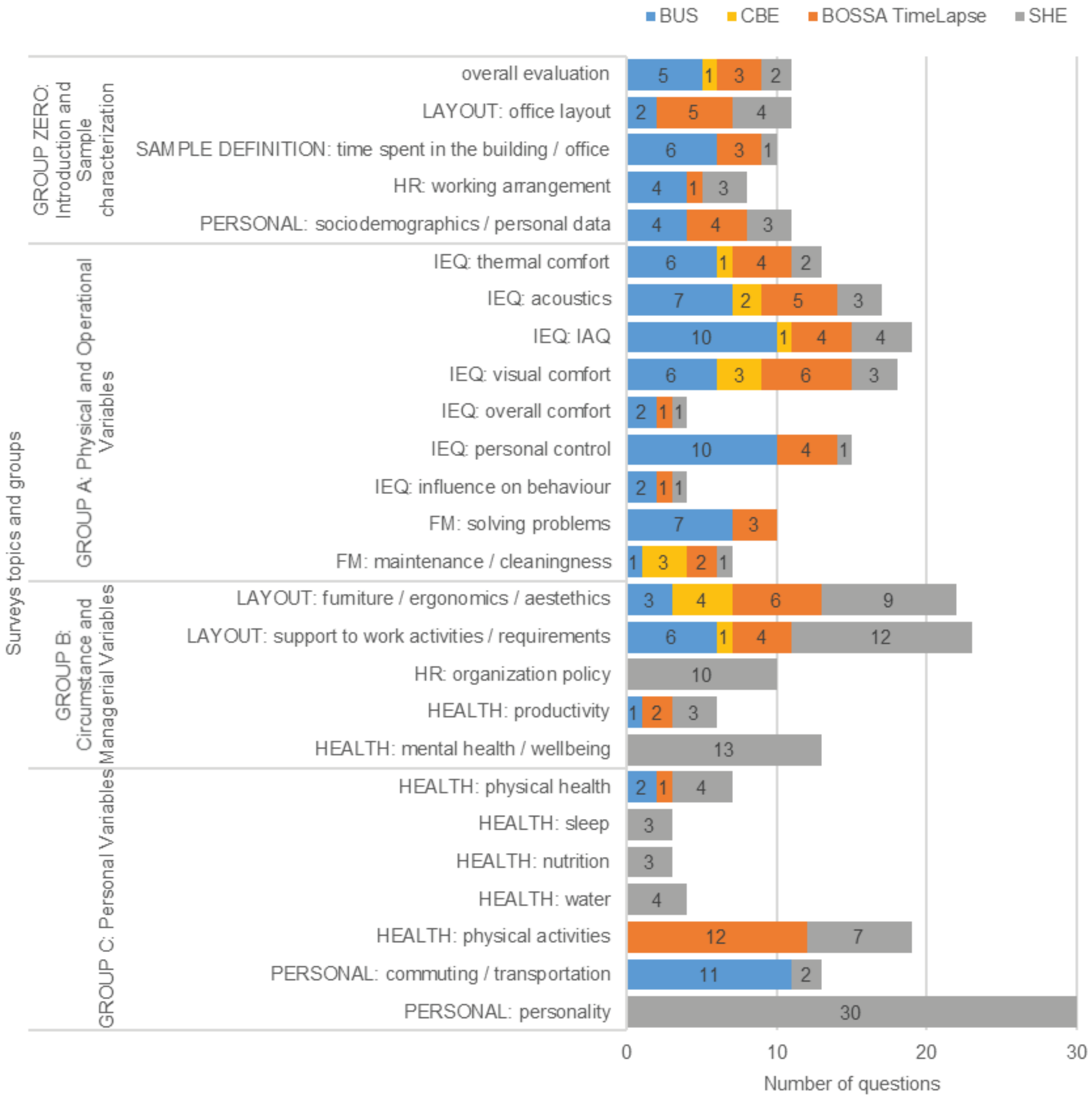
4.1 INSTRUMENT DEVELOPMENT

The questionnaire development process went through the following steps: comparative analysis of reference user satisfaction surveys selected from literature review; exploratory interviews with HR managers to understand industry practices and possible limitations for the application of the proposed method; filter and definition of the list of relevant questions for application considering the context of the framework proposal; delimitation of questions' hierarchy, from domain identification to detailing discomfort issues and/or follow up questions; definition of question items and measurements scales; and on-line form and interface set up. Items 4.1.1 to 4.1.6 present general guidelines that were considered for each step of questionnaire development, respectively.

4.1.1 Comparative analysis of reference user satisfaction surveys

Three out of four main user satisfaction surveys were selected from literature as references: BUS (presented in item 2.2.2.1), CBE Occupant Survey (presented in item 2.2.2.2), BOSSA Time Lapse (further referred as BOSSA TL, item 2.2.2.3) and SHE (item 2.2.2.4). Reference questionnaires were screened and analyzed considering subjects approached, extent and logical structure in organization of questions, as well as survey elements and language differences between instruments. From screening analysis, 26 categories of subjects approached could be identified, as presented in Figure 17, and questions related to the same subject were grouped. Some of the questions were connected to more than one category. For instance, from SHE survey, questions related to access to pleasant external views (e.g., water, greenery, sky) could both be considered in the "*IEQ: visual comfort*" and "*HEALTH: mental health / wellbeing*" categories. Since there are more subjective aspects related to the external views available in the work environment than those related to illuminance levels and natural light availability, it was kept in the latter category. From Figure 17 it is possible to note a trend of interest in aspects related to occupant health and wellbeing in the workspace by the increase in the number of questions related to these topics from BUS to SHE surveys. Total number of questions were counted regardless of branching structure and/or follow up questions.

Figure 17 - Subject categories and number of questions identified from reference surveys.



The first group, named GROUP ZERO, comprises overall building evaluation together with questions that seek to characterize the research sample in terms of work arrangements, layout distribution and time spent in the office and/or workstation. Next is GROUP A, which gathers questions about user satisfaction related to physical and operational variables of the built environment, such as Indoor Air Quality (IAQ) and thermal, visual, and acoustic comfort domains. To this group, topics such as perception of personal control in the workplace and influence of IEQ parameters on behavior were added. Building operation aspects, e.g., solving problems and maintenance, also belong to this group. Further on, GROUP B focuses on user perception about subjects both related to circumstantial and managerial variables. Circumstantial variables are understood as topics related to the built environment which were, at some point, defined by the own company when creating their office space, deliberately chosen considering corporate culture. As an example, one can think about two different companies who occupy the same building, with similar architectural features but in different floor levels. Although they had similar spaces to work with when designing their internal office, they may differ on several aspects, such as layout distribution (open plan or internal partitions; fixed or non-fixed workstations), furniture (regular or sit-to-stand desks) and internal finishes (vibrant colors, greenery, amenities) and so on. Managerial aspects are those not related to the built environment, and which follow corporate policies. Finally, GROUP C comprises questions related to personal and health aspects. This question group was mostly present on SHE questionnaire, which is the occupant survey that focuses on health and wellbeing. This group comprises topics such as physical activities, sleep quality, commuting etc., and may help clarify, for instance, physiological aspects influencing comfort levels and sleep quality effects on perceived productivity, amongst others.

4.1.2 From Organizational Climate Survey to IEQ survey

From the analysis of reference questionnaires, it was observed that most questions from GROUP B addressed issues related to corporate policies. It is acknowledged that work arrangements (such as flexible working hours and remote work) and benefits (such as parental leave, health insurance, commuting vouchers, etc.) are factors that influence wellbeing of workers in general, some of them even being labor rights that must be mandatorily assured to employees. These topics, however, fall outside the scope of the built environment, moving towards organizational aspects. In that matter, exploratory interviews were carried out with HR managers to understand industry practices and raise necessary stimuli and possible limitations for the application of the proposed method. Six HR managers from different industries (law, finance, technology) and varying scales (start-ups with 50 to 100 employees and large corporations with 90,000 employees) were interviewed. Interviews focused if and how employee satisfaction and productivity are tracked and evaluated within company' organization policies; and the kind and frequency of surveys are carried with employees, if any.

Regarding occupant surveys and employee satisfaction, e-NPS (employee Net Promoter Score) was unanimous as an indicator adopted. Inspired by the NPS (Net Promoter Score) whose original application was to measure customer satisfaction through a single question: "*On a scale of 0 to 10, how would you recommend [company] to a friend or colleague?*", the e-NPS uses the same calculation method to rate whether the company is a good place to work by asking employees "*On a scale of 0 to 10, how would you recommend [company] to work for?*". Employees are classified into three groups: detractors, passives, and promoters, with a scale of evaluation for the final index, which is disclosed as a key value to benchmark with other companies. Beyond e-NPS, organizational climate surveys were cited as a well-established method of keeping contact with employees. Application varies in frequency (quarterly to annually) but belong to companies' routine.

For employee productivity monitoring, all respondents mentioned engagement rates. Employee engagement is a concept that describes the individual's involvement and satisfaction with as well as enthusiasm for work (MACEY; SCHNEIDER, 2008) and has been part of management theory since the 1990s. It is common sense between the interviewed HR managers that engaged employees are more likely to be productive and present higher performance. Literature suggests that there are predictors to employee engagement. One of the industrial practices observed for this type of monitoring consists of application of weekly surveys to continuously track employee's opinion. The questions are grouped into twelve groups of engagement predictors, called "dimensions" (*Alignment with the company, Wellbeing, Career, Professional Development, Ambassadorship, Structure, Feedback and Recognition, Happiness, Innovation, Justice, Leadership, Interpersonal Relationship*) (PULSES, 2022). The entire survey consists of 156 questions, randomly sent in batches of 10 to 15 questions per week to employees. As a result, best practices are recommended for those dimensions with lower scores. When comparing dimensions, results indicate "Structure" as the third most impactful predictor of employee engagement, behind

"Justice" and "Innovation", while "Happiness", "Interpersonal Relationship", and "Wellbeing" are among the last.

From the HR interviews, it was observed that employee engagement is relevant for companies, and that maintaining high levels of engagement is a crucial matter in people management practices. From twelve identified dimensions, subjects identified in the reference questionnaires such as wellbeing, mental and physical health, work arrangements, commuting, etc. are scattered among them. This means that those subjects are already considered in more comprehensive metrics and evaluations by HR managers regarding engagement rates. "Structure" is highlighted for evaluating adequacy of work conditions related to lighting, temperature, and workload. This dimension includes building and facilities management, acknowledging it belongs to the universe of employee engagement predictors, as well as under the scope of people management, which is aligned with the objectives proposed in the assessment framework. Therefore, this type of monitoring can work as a connection, since it shows common points that could open space for in-depth IEQ evaluation. In other words, the employee engagement survey can also work as a bridge to the improvement of facilities management and BPE. This type of incentive may be enough not only to stimulate monitoring, but also to generate operational changes by the facilities management team.

Table 8 – Transition question from organizational climate survey to IEQ survey

#	Question	Items	Index
Q0	How would you rate your satisfaction with your work environment physical conditions (temperature, indoor air quality, lighting, and acoustics) to perform your activities?	Scale 0 to 10	IEQ Satisfaction Score

From this scenario, two milestones for questionnaire development were drawn. First, questions from GROUP B addressing organizational policy, productivity, mental health etc. were excluded, focusing only on aspects directly related to the built environment and BPE. Second, a transition question focusing on IEQ satisfaction was created to link the organizational climate survey and the occupant satisfaction survey within the framework. The aim is to add this question in the standard organizational climate survey and use it as a trigger to identify dissatisfaction. For this, it is proposed a similar scale adopted in the organizational climate survey (0 to 10), and which would generate an "IEQ Satisfaction score" every time the survey is applied. Whenever the answer is lower than 7-score, IEQ occupant satisfaction survey is triggered, following the branching structure proposed and further presented in section 4.1.4. The proposed question is shown in Table 8 and in the first column of questionnaire map in **Erro! Fonte de referência não encontrada.**.

4.1.3 Question filtering and selection

From this scenario and with compilation of questions from reference questionnaires conducted, it was possible to filter the most appropriate subjects to be addressed with the proposed instrument, considering the main goals of *Standard* module. Bearing in mind that this questionnaire aims to generate a diagnosis based on the user's perception of their workplace, it is necessary to ask all relevant questions so that the next module can focus on specific topics and only approach users regarding critical points identified.

From GROUP ZERO, a minimal definition of the space where participants are working from (and sharing their perception about) was included as opening questions. Since responses are anonymous, those are the work environment physical characteristics required from participants to inform. It is assumed that, by stratifying the sample according to office layout type, workstation proximity to windows, and approximate daily time spent at workstation might help to cluster results for comparative purposes and possibly define weighting methods of the outcomes. Apart from that, the proposed instrument focus on extracting only subjective data from participants, that is, information that cannot be obtained in a way other than asking them directly. Next, from GROUP A, it was chosen to approach each IEQ domain individually, following the approach from reference questionnaires. For each domain, specific related topics were included, as well as perception of personal control with systems and/or attributes existing in the assessed work environment (air conditioning, windows, shading, etc.). Afterwards, overall comfort evaluation, operational problems solution, and influence of IEQ on behavior are raised. From GROUP B, visual and acoustic privacy issues, and hierarchy of importance of IEQ domains where selected. GROUP C questions were not included since it is understood that participants' personal health issues, besides consisting of a delicate matter to be approached at this stage, can be subject of further detailed studies if critical points are identified in each domain. Considering that specific building standards (ABNT, 2021, 2022; EN

ISO, 2012; ISO, 2021) do include assessments that address these topics, such personal information can be required at the discretion of the specialist.

Socioeconomic and demographic characteristics data would only serve to characterize research samples and that must be clear to all participants. Since the targeted audience of this assessment consists of office workers, and that the HR sector must be involved in the whole evaluation process, it is suggested that socio-demographic data (such as age, gender, education level, job title and income) from employees must come from the personal admission registration files database, after consent form authorization. Privacy concerns must be carefully taken by assigning each participant a random and unique identification for data collection, which should be linked to survey responses and eliminating evidence providing the participants' identities.

4.1.4 Questions' hierarchy: domain identification to detailing discomfort

Criteria for questionnaire preparation also considered engagement rates, a critical point widely noted in occupant satisfaction studies. To keep survey as short as possible will generally result in a larger sample size and quality responses. Thus, once the relevant topics to be addressed were defined, it was necessary to shorten the list of questions. Challenge was to adapt the questions into a structure that was brief enough not to wear out participants and yet provide the required information. Therefore, to reduce mental effort and fatigue from going through unnecessary questions, it was adopted a branching structure, which allows driving users to specific and/or follow up questions only when applicable.

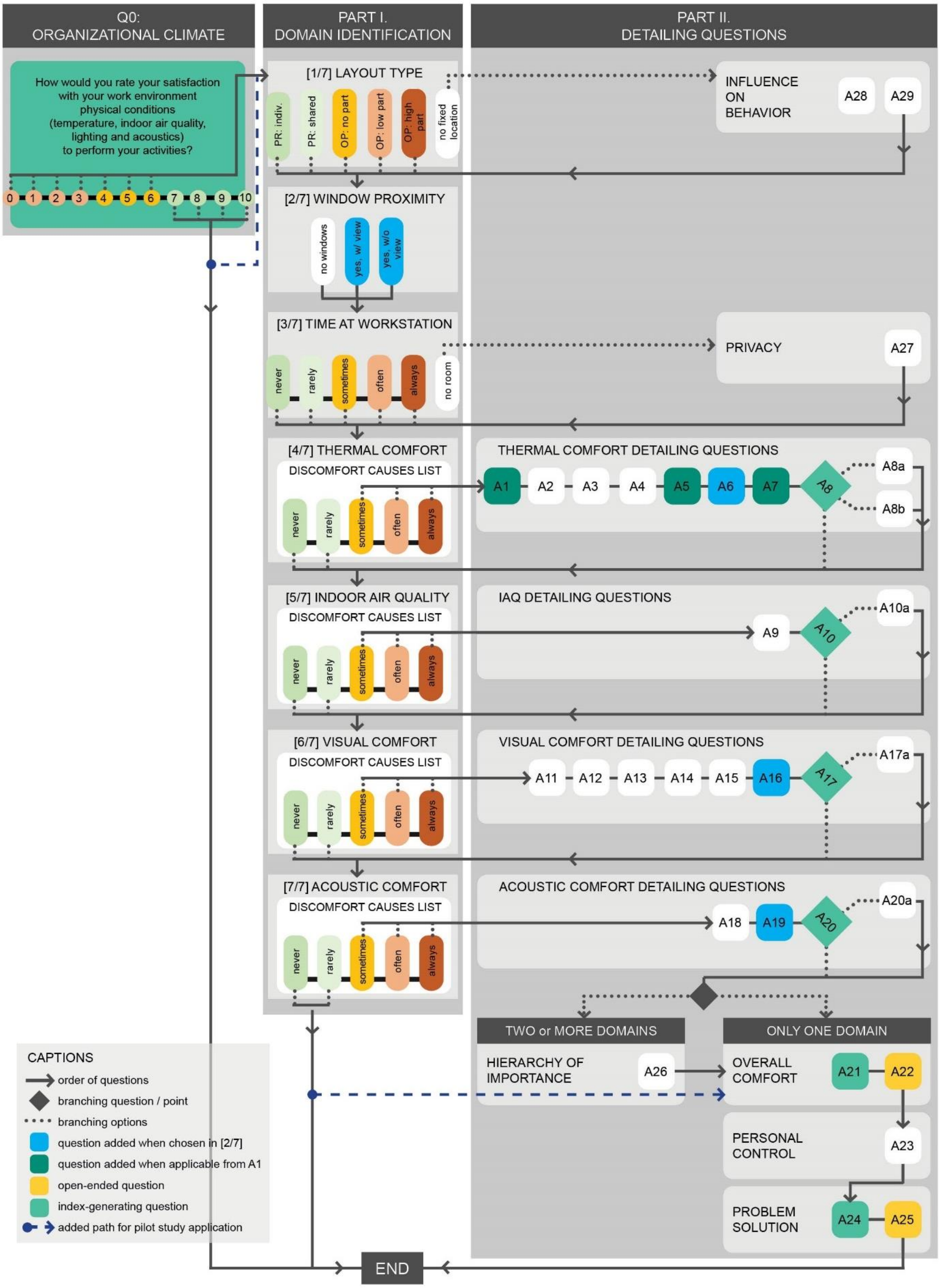
In that matter, the main structure of the questionnaire was divided into two hierarchical parts, as shown in the questionnaire map in Figure 18. Part "I. DOMAIN IDENTIFICATION" and presented in Table 9, consists of the minimum mandatory questions that all participants are required to answer. It is composed of seven groups of questions aimed at identifying which IEQ domain is causing discomfort, while part "II. DETAILING QUESTIONS" (presented in APPENDIX A) gathers the respective in-depth questions of each group, whose number of questions varies between three and eight (see Figure 18) and which basically consist of the common scope of questions identified in the reference user satisfaction surveys. In part I, after characterizing the type of office layout, proximity to windows and estimated time spent at the workstation in questions 1 to 3, lists of possible causes of discomfort for each domain were arranged in questions 4 to 7. Whenever any item in this list of causes is indicated with high frequencies (e.g., *I feel discomfort with ... always / often / sometimes*) for each IEQ domain, part II with detailed questions regarding this domain is triggered. If the lower two points (*never / rarely*) were indicated for the entire list of causes of discomfort in part I, detail questions from part II of that domain are bypassed, as illustrated by dotted lines in Figure 18. In other words, part I works as a filter for the detailing questions in part II: it dismisses participants who do not indicate discomfort (and therefore are comfortable with their environment status) from going through such questions; and whenever discomfort is detected, part II is triggered allowing to collect more information. This was the solution proposed to reduce the questionnaire extent, addressing all relevant topics identified from the analysis of the reference questionnaires.

Same principle applies inside detailed questions regarding satisfaction levels with a specific domain: by rating satisfaction with a low score (1 or 2 points), it is required for participants to review the discomfort causes list; for 3 to 5 points of satisfaction, the follow up section is bypassed. It was also used for adding or dismissing detailed questions based on previous responses. For instance, when a participant indicates occupying an office room without windows, branching structure skips automatically any specific questions regarding window control for all IEQ domains' detailed questions (illustrated with blue boxes in Figure 18). Influence on behavior question is only asked when "no fixed location" is chosen, trying to understand what the main aspects are one is looking for when choosing their workstation. Privacy issues are also asked when some specific activity areas do not exist in the office. Another filter provided by the branching structure consists of IEQ domains' hierarchy of importance. This group of questions is only triggered when discomfort is identified in two or more different domains. All instrument' branches are blind to participants.

Table 9 - Part I. DOMAIN IDENTIFICATION questions.

#	Question	Items
[1/7]	LAYOUT TYPE	
	Please select the office layout which best illustrates your workplace.	*[illustrations with brief descriptions]* a) Private room: individual b) Private room: shared with other colleagues c) Open plan: no partitions d) Open plan: with low partitions: I can see my colleagues and surroundings even when I am seated e) Open plan with high partitions: I need to stand up to see my colleagues and surroundings f) no fixed location: I don't have a desk assigned to me; I can choose my workstation every day
[2/7]	WINDOW PROXIMITY	
	Are there windows and/or other glazed areas in your workplace?	*[illustrations with brief descriptions]* a) Yes, I can see outside even when I am sitting at my workstation b) Yes, but they are too far away from my workstation c) There are no windows or other glazed areas at my workplace
[3/7]	TIME AT WORKSTATION	
	On a typical working day, how often do you estimate you use... 1. Your workstation? 2. Rotating and/or non-fixed workstations? 3. Specific areas to develop group and/or dynamic activities? 4. Specific areas to develop individual and/or focused activities? 5. Conference and/or meeting rooms? 6. Outside the office for external activities?	a) always b) often c) sometimes d) rarely e) never f) my office does not have this type of room
[4/7]	THERMAL COMFORT	
	Regarding the thermal environment of your workstation, do you usually experience any of the following? *[discomfort causes list]* 1. I feel hot discomfort 2. I feel cold discomfort 3. I feel discomfort because there is too much wind 4. I feel discomfort because there is not enough wind 5. Direct sun disturb me 6. There are nearby surfaces (floors, walls, etc.) that are too hot or too cold 7. I feel discomfort due to cold or heat in specific parts of my body (hands, feet, neck, head, etc.)	a) always b) often c) sometimes d) rarely e) never
[5/7]	INDOOR AIR QUALITY	
	Regarding the Indoor Air Quality near your workstation, do you usually experience any of the following? *[discomfort causes list]* 1. I feel discomfort due to odors 2. I feel discomfort with stuffy indoor air 3. I feel discomfort with too dry or too humid indoor air 4. I feel discomfort due to dust	a) always b) often c) sometimes d) rarely e) never
[6/7]	VISUAL COMFORT	
	Regarding visual comfort at your workstation, do you usually experience any of the following? *[discomfort causes list]* 1. I feel discomfort with a too bright room 2. I feel discomfort with a too dim room 3. I feel discomfort with glare 4. I feel discomfort with reflections on my computer screen 5. I feel discomfort with flickering lights 6. I feel discomfort because I cannot differentiate objects (high and/or low contrast)	a) always b) often c) sometimes d) rarely e) never
[7/7]	ACOUSTIC COMFORT	
	Regarding the acoustic comfort at your workstation, do you usually experience any of the following? *[discomfort causes list]* 1. I feel discomfort with noise from colleagues' conversations 2. I feel discomfort with equipment noise 3. I feel discomfort with external noise, coming from outside	a) always b) often c) sometimes d) rarely e) never

Figure 18 - Questionnaire map of hierarchy and bypasses.



In summary, within the proposed survey structure, all participants would go through Q0, which is the transition question from the organizational climate survey to IEQ satisfaction survey. Only those participants that indicate a score between zero and 6 would be directed to part I, and if discomfort was identified in any domain, they would be further directed to A21 in the detailing of part II, as can be noted by following continuous and dotted lines on the map shown in Figure 18. It is worth stating that, for the pilot study (further presented in item 4.2.3), paths were added (blue dashed lines in Figure 18) that directed participants to part I even if a score above or equal to 7 was indicated on the Q0; and those who indicated no discomfort in part I would answer the detailing questions A21 to A25. In other words, all participants in the pilot study answered both questions Q0 and A21 to A25. This was chosen so that all participants can have a chance to evaluate the questionnaire.

4.1.5 Question elements

Regarding questionnaire elements, that is, questions and items themselves, criteria for selection of questions from reference surveys were the understandable language analysis and avoidance of ambiguity. Most of the questions were reviewed aiming to achieve a clear and accessible language and avoiding technical jargon that could drive doubts or misunderstandings. Awareness of bias and emphasis were also considered since word choices might drive responses.

For development of measurements and scales, it is important to understand what type of data is being collected to be compared and analyzed. In that matter, as stated previously, it was considered that indication of absence of discomfort with any IEQ domain in part I would dismiss the need to deepen the diagnosis on that subject, focusing only on discomfort-causing issues. Therefore, the proposed method of measuring discomfort in a way participants could easily relate in their work routine is through a preliminary list of possible causes of discomfort, measured with a frequency 5-point ratio scale (*always, often, sometimes, rarely, never*). It was assumed that a frequency scale might be clearer for participants to initially quantify their discomfort with each topic. Also, it could provide an easy-to-understand outcome for managers to evaluate. For instance, "*I feel discomfort by ... always*" must give more accurate status then an intensity scale, such as "*I feel extremely discomfort by …*". On part II, 5-point scale were also kept as a standard. However, at this point each topic was adapted to its subject (e.g., *hot / cold; light / dark; inadequate / adequate; disturbing / not disturbing; comfortable / uncomfortable*), as exemplified in Table 10.

Table 10 – 5-point scale examples adopted in parts I and II.

#	Acoustic Comfort Questions	Items
	Part I. Domain Identification	Frequency scale
[7/7]	Regarding the acoustic comfort at your workstation, do you usually experience any of the following? *[discomfort causes list]* 1. I feel discomfort with noise from colleagues' conversations 2. I feel discomfort with equipment noise 3. I feel discomfort with external noise, coming from outside	(1) always (2) often (3) sometimes (4) rarely (5) never
	Part II. Detailing Questions	Disturbance scale
A18	At your workstation, how would you describe or rate... 1. Noise from colleagues: conversations that I can understand what is said 2. Noise from colleagues: background conversations that I can't understand what is said 3. Noise from colleagues: keyboards, footsteps, opening and closing drawers, etc. 4. Noise from the building: air-conditioning 5. Noise from the building: other equipment 6. Noise from the building: telephones ringing 7. Noise from surroundings: external noise, coming from outside	(1) not disturbing (2) (3) (4) (5) disturbing

Table 11 – Satisfaction with overall comfort question.

#	Question	Items	Index
A21	All things considered, please indicate your level of satisfaction with your workstation overall comfort.	Scale 0 to 10	Overall Comfort Satisfaction Score

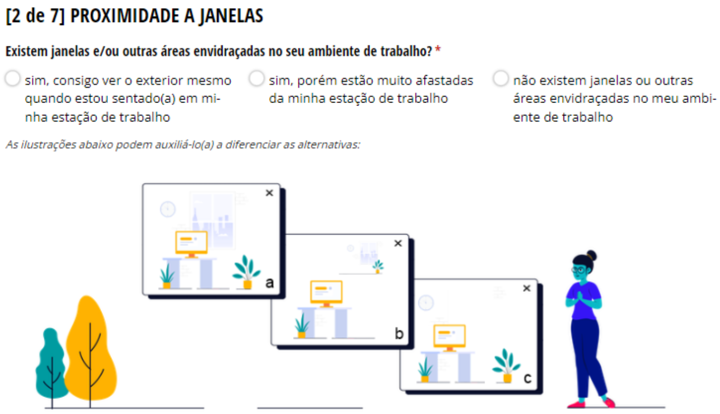
In addition to the 5-point scales, it was also adopted a 0 to 10 scale to assess overall comfort (Table 11), resembling the adopted in organizational climate surveys, in which participants evaluation generates an index. The intention was to propose an "Overall Comfort Score" from the average of answers and use it as a performance indicator from the first module of the framework, giving an easy-to-understand outcome to both users and managers. Despite requiring more effort and increasing response cost, open-ended questions regard overall comfort and operational problems solution (illustrated with yellow boxes in Figure 18) are asked to reinforce the survey's interest in participants' opinion. Due to its extent, the final version of questions and its scales from part II are presented in APPENDIX A.

4.1.6 On-line form and interface set up

Once question items and the branching structure were designed, a few on-line form platforms were tested to define which could be the most appropriate for test applications. Cognito Forms (COGNITO LLC, 2022) free version was chosen since it allows the branching structure conditions flexibility required by the previously presented questions' hierarchy, beyond its user interface being simple and intuitive.

Figure 19 – Office layout types illustrated.

Figure 20 – Window proximity illustrated.



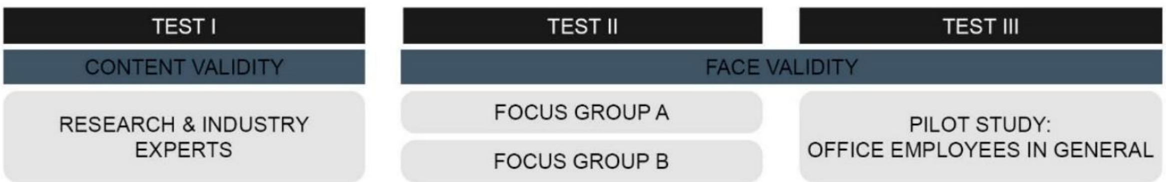
A few visual cues and illustrations were developed trying to help users with technical jargon, since describing architectonic settings textually may become somehow tricky for participants who may not have any experience on defining their environment or its measurements. These cues can help to clarify important details that characterize the space, encouraging participants to provide consistent answers to all questions. For instance, Figure 19 illustrates the differences between office layout types, making it easier and faster for participants to understand the type of workplace they are assessing. Figure 20 shows a reference for window proximity by using window views from one's workstation. This kind of visual cue might generate answers that are more reliable then asking participants, for instance, what is the distance in meters between their workstation and the closest window. The final version of the survey instrument, with proposed questions and items was set on the platform and submitted to testing processes, described next.

4.2 INSTRUMENT TESTING PROCESS AND RESULTS

Since the complete proposed assessment framework involves long-term phases, it is suggested for the occupant survey instruments to be separately and independently tested. This suggestion seeks to identify weaknesses and necessary adjustments prior to implementation of the entire framework. Therefore, this research focused on testing the developed occupant satisfaction survey, described to fit within the framework in item 3.3.1. Development and validation of real-time occupant interaction as described in item 3.3.2, as well as further application of all survey instruments following the framework guidelines must be carried out in future works, in order to evaluate it as a whole.

The effort of preparing and testing the longitudinal survey instrument in a pilot study was to provide a first contact with targeted survey participants, that is, office employees in general, gathering preliminary validity evidence considering the objectives of the delimited framework. Tests carried are illustrated in Figure 21. Instrument adjustments and corrections raised after each test were carried prior to next stage, except for the pilot study. Therefore, results described from Test III application consist of a critical review of the instrument. Field building measurements were not collected for any stage of instrument' test. Next items describe the testing stages and results obtained.

Figure 21 – Instrument testing stages.



4.2.1 Test I: Research and industry experts

For content validity test, the proposed instrument was submitted to review of experts of each IEQ domain to assess the addressed content. This validation involves an evaluation of proposed questions aiming to assure whether all variables inherent to each IEQ domain were contemplated and whether the way topics were approached are adequate for generating a consistent diagnosis of that domain.

Table 12 – Content validity recommended adjustments.

IEQ Domain	**Experts consulted**	**Recommended adjustments and/or suggestions**	
		Part I. Domain identification	**Part II. Detailing questions**
Thermal comfort	1 post-doctoral specialist researcher. 2 PhD researchers.	Recommendation that discomfort from personal control to be addressed only on detailing questions.	Alignment of the scales from the revision of the specific standard was discussed.
Indoor Air Quality	1 lecturer and researcher.		Suggestion to separate aspects related to discomfort caused by dust.
Visual comfort	1 lecturer and researcher. 1 post-doctoral researcher.		Recommendation for artificial and natural lighting topics to be treated independently, since discomfort caused by artificial lighting should generate relevant data for operators. On the other hand, daylighting levels are more sensitive to time variation (e.g., morning and afternoon; summer and winter). Therefore, identification of the period of discomfort would be a relevant data to be provided in the set of diagnostic outputs to guide the following decision making.
Acoustic comfort	1 specialist practitioner, MSc, with 22-year experience on acoustics.	To add discomfort caused by noise generated by colleagues.	To deepen investigation of discomfort caused by noise generated by colleagues' conversations, both by background noise and speech intelligibility. This aspect is also related to acoustic privacy in work environments.

Therefore, researchers and industry experts were invited, and the complete questionnaire was made available for previous appreciation, followed by a discussion regarding the topics included and its relevance for the framework assessment. Table 12 indicates individual and/or teams consulted, as well as requested adjustments and corrections raised for their respective IEQ domain, which were carried out prior to face validity tests, presented next.

4.2.2 Test II: Session groups application and discussion

After implementation of suggested adjustments, first stage of face validity test was started. Face validity involves a subjective evaluation of proposed questions and their respective items (e.g.: language adopted, proposed scales, questionnaire extent) to determine whether they seem logical, clear, and appropriate to the concepts studied, as well as testing user experience with the on-line platform and its interface (branching structure, visual cues). For that, two rounds of questionnaire application on the on-line interface were carried with groups of volunteers, followed by an exploratory discussion. Group A consisted of ten laypersons while Group B had six researchers with experience in IEQ field research and occupant survey applications. Questionnaire application was held simultaneously within each group and after all participants submitted the form, a discussion regarding their impressions was conducted.

Regarding understanding of the adopted language, two important points were raised by Group A. The first was related to existing double negatives in some of the questions, for instance, "*I feel discomfort for not having ... never"*. Second, regarding the length of the sentences in the questions, mainly of those about perceived control. Also, it was discussed that, when asked about their "satisfaction" level with any aspect, the term was understood as something personal, involving expectations and opinions; while the term "suitable" was understood as a functional aspect, and therefore, a minimum parameter to be achieved. As an example, it was mentioned that the lighting could be suitable for the activity performed (that is, adequate levels of illuminance) but not necessarily satisfactory (comfortable, desirable).

Within Group B, aspects such as inversion of scale position was discussed, since the maximum score or the positive evaluation varied from left to right in between groups of questions. It was recognized that these would be different techniques to verify participant's level of attention, both with positive (to avoid indicating the same answer on purpose) and negative sides (mistaken evaluation due to lack of attention in the inversion of the scale and/or habit bias). It was also discussed the total questionnaire length, its time to be completed, and whether the detailing questions might create fatigue on participants. It was suggested that any mention of remote work was excluded, as well as to add clearer guidance to consider moments of working at the office when answering the questionnaire, highlighting the research interest on the work environment. The final questionnaire version was reviewed based on the comments and observations indicated at the end of this process. Finally, a wider application was conducted with office employees in general to simulate real application, described next.

4.2.3 Test III: Pilot study - office employees

The second stage of face validity test conducted in this research aimed on testing the instrument on real life context. Therefore, targeted population was office employees in general, and participants were asked to fill in the questionnaire considering their actual workplace. At the end, they were invited to answer additional questions regarding the instrument itself, assessing the questionnaire regarding its organization, objectivity, clarity, readability, and content comprehension, assigning each item a score from 1 to 5, as presented in Table 20 in APPENDIX A. Also, their opinion about the suitability of the topics covered on the survey to assess satisfaction with the work environment IEQ was asked. An open-ended question was also added for indication of any missing topic and/or other relevant contribution. Participant recruitment was done via institutional mailing lists, social media, and others, since there were no restrictions related to disclosure of the research. After checking the consent form, it was estimated the questionnaire to take from seven to twenty minutes to be completed, due to the branching structure described previously on item 4.1.4. Participant recruitment managed to reach 115 office employees volunteers in two weeks of data collection. Database was exported from on-line survey platform into standard spreadsheets and adopted in subsequent study analyses. Identifiable data from participants (e-mails) were locally stored and only the researcher have access to them. For data treatment, pseudonym codes were assigned to each participant, who are further identified exclusively by this code. This pilot study was submitted and approved at the university' research ethics board (*Comitê de Ética em Pesquisa com Seres Humanos*, CEPSH-UFSC) under register (*Certificado de Apresentação de Apreciação Ética*, CAAE) 59892022.3.0000.0121.

It is important to remember that the data obtained in this pilot study refer to several distinct and unidentified work environments. Therefore, data cannot be grouped and evaluated together to draw conclusions about the level of satisfaction in a given work environment, mainly from detailing questions (part II). However, the answers obtained can give evidence as to whether the instrument was in fact functional and clear to participants, as well as possible performance indicators that could be extracted from survey to provide a consistent workplace IEQ satisfaction diagnostic. Therefore, analysis of pilot study outcomes focused on evaluating the instrument application. Results are presented and discussed next.

4.2.3.1 Defining research sample

For defining pilot study participants' sample, they were asked to indicate their age range, level of education, and gender. Since the pilot study required recruitment of office employees in general, and this data could not be requested directly from their employers (as expected within the proposed assessment framework), such questions were added. Results are presented in Figure 22 and Figure 23, and further analysis group open plan layout types (*no partitions*, *low partitions,* and *high partitions*) and private rooms (*shared* and *individual*), since individual samples are quite small. Such stratification is also intended to evaluate IEQ expectation differences between occupants located in private offices and in a dense, open-plan office space.

Figure 22 – Research sample: office layout types.

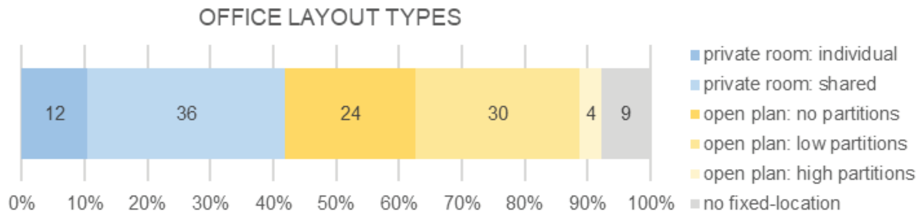
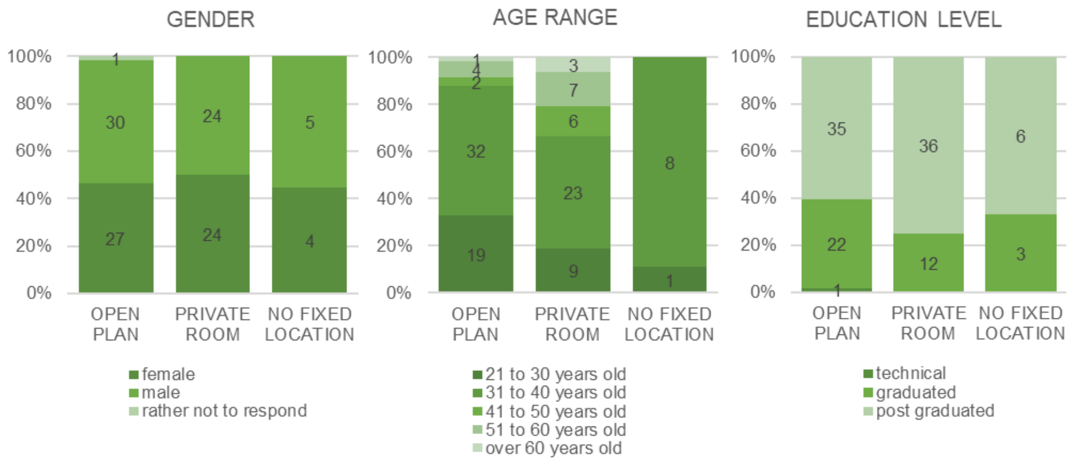


Figure 23 – Research sample: sociodemographic data.



All layout types showed a balanced gender distribution. Participants' age range is mainly concentrated between 31 and 40 years old. However, open plan layout shows a trend of occupation of lower ranges (21 to 30 years old), which is predominant in no fixed locations, while in private rooms it tends to increase towards higher age ranges (over 40 years old). As for educational levels, it is possible to observe a predominant bias of post-graduated and graduated participants. There were no respondents under 20 years old (e.g., interns) as well as education below technical level. Future studies and instrument applications should be aware of these groups, since it should be as comprehensive as possible.

4.2.3.2 Instrument evaluation

This item discusses the results of the participants' instrument evaluation. The mean values obtained for each item are presented in Table 13. Instrument adequacy to evaluate satisfaction with IEQ obtained an average score of 4.75. "Organization" was the best rated item, while "objectivity" was the topic that presented the lowest average, but still a high score. Comments obtained from open-ended question consisted of subjects that were not addressed within the questionnaire, in which "ergonomics", "view quality and sunpath", and "periodic cleaning and sanitization" were mentioned. In addition, there were comments on improvements for the instrument itself. For instance, it was suggested to create hover boxes with detailed explanations for lay people. This may be an indicative that visual cues and illustrations might not be clear enough, or technical jargon was not fully eliminated from questions. Another point mentioned was the alternated scale position between questions: "*I had to pay attention to do not give a low score for something I was comfortable with*". Regarding the length of the questionnaire, only one participant (who indicated discomfort with all four domains and, thus, went through all detailing questions) clearly stated "*too long*".

Table 13 – Mean scores from questionnaire assessment.

	Organiza-tion	**Content comprehen sion**	**Readability**	**Clarity**	**Objectivity**	**Suitability of topics covered to assess satisfaction with the work environment IEQ**
Mean	4.83	4.79	4.72	4.69	4.55	4.75

Two reasons can be assumed for the lowest average rating for "objectivity". The first is. And second is due to the illustrations and visual cues, which gave a gamified aspect of the instrument and were proposed intentionally to make the response process more interactive and, desirably, increasing participant engagement with the survey. It is agreed that a survey instrument with a question list-format can be more objective. However, this format also restricts some clarifications, as indeed mentioned by participants in the open comments indicating that further explanations of what was being asked were missed. That matter may also justify the second lower mean evaluation rate of "clarity" item. For future versions of the questionnaire, a review focused on counterbalancing objectivity and clarity is required, as well as the illustrations and visual cues presented. Regarding the subjects missing from the questionnaire indicated in the comments, it is important to emphasize that the survey focused only on the IEQ parameters (thermal, visual and acoustic comfort and IAQ) of built environment. Therefore, ergonomics and cleanliness were not covered, even though both were subjects addressed in the four reference questionnaires. External views, on the other hand, despite related to visual comfort, consist of a building characteristic that cannot be changed by building management or HR. Although it is relevant to understand the level of satisfaction with the existing view, an indication of dissatisfaction with this topic does not generate any alternative of improvement. Therefore, it was chosen to prioritize those items linked to possible corrective actions within the building occupancy phase. The future inclusion of these and other specific items, however, is not fully discarded since it may become necessary if frequently addressed by participants with the broader questionnaire application.

4.2.3.3 Satisfaction and overall comfort evaluation

This item analyzes satisfaction with the work environment (Q0) and overall comfort evaluation (A21), which were the questions set to be evaluated with 0 to 10-scales to generate an “IEQ Satisfaction Score” and an “Overall Comfort Satisfaction Score” and be used as indicators.

From total sample, 81% of participants scored 7 or higher for their workplace IEQ satisfaction evaluation (Q0). Figure 24 presents the number of times each score was assigned by participants to evaluate IEQ satisfaction with their work environment, split by layout types. Green bars (scores 7 to 10) represent those cases exempt from further investigation; while yellow (4 to 6) and orange (0 to 3) bars represent cases when part I of the questionnaire would be triggered (see map on Figure 18). From the instrument first main branch structure (Q0 to Part I), 17% from open plan sample, 23% from private offices and 11% from no fixed location would be driven to further investigation regarding satisfaction with IEQ. A question was raised whether there would be differences between evaluation from total sample and from each type of layout, concerning an "IEQ Satisfaction Score" to represent the whole office. To analyze it, ANOVA tests were performed comparing layout types' averages. Results in Table 14 shows that *f* is not higher than *f* critical, meaning averages do not differentiate between themselves and, therefore, a global index is representative of the whole office. Complementarily, same test was performed for Overall Comfort Satisfaction evaluation (A21), with the same results. Score distribution of Overall Comfort Satisfaction evaluation by office layout types are presented in Figure 25. From Figure 24 and Figure 25, it was brought to attention that score distribution is concentrated from 4 to 10 grades. This may be an indicative that broader scales such 0 to 10 to be inadequate for this type of evaluation. Some possible reasons range from participants' difficulty to differentiate between too many values (for instance, which aspects differentiate a 6-score from a 7-score), until psychosocial aspects such as resistance to attribute lower scores to their office environment. Adjustment of these questions to the 5-point scale should be reevaluated on future works.

Considering the pilot study, which took all participants to evaluate both IEQ satisfaction and overall comfort, a hypothesis raised was that after going through the entire list of causes of discomfort in part I and therefore reflecting on their feelings in their work environment, the score comparison between IEQ satisfaction and overall comfort satisfaction might be somehow unbalanced. Discomfort list might even act as negative bias towards lower overall comfort scores. To assess this, correlation tests were conducted between Q0 and A21 ratings for each office layout type. From graphs presented in Figure 26, private offices showed higher correlation rates, with (88%, with R^2=0.74). Open plan layouts showed lower correlation (58%, with R^2=0.54), due to few assessments with very different scores. For no fixed location layouts, correlation rate reached 51%, with R^2=0.63. Such figures, especially for private offices, incites reflection on whether this correlation fit on the one-dimensional quality category from Kano model, in which satisfaction is linearly dependent upon overall comfort, which could be followed on future studies applying the questionnaire. Also, no indicative of bias from the discomfort list causes was observed from the pilot study sample, since correlation trends were always positive.

Figure 24 – Score distribution for IEQ Satisfaction evaluation (Q0) by layout type.

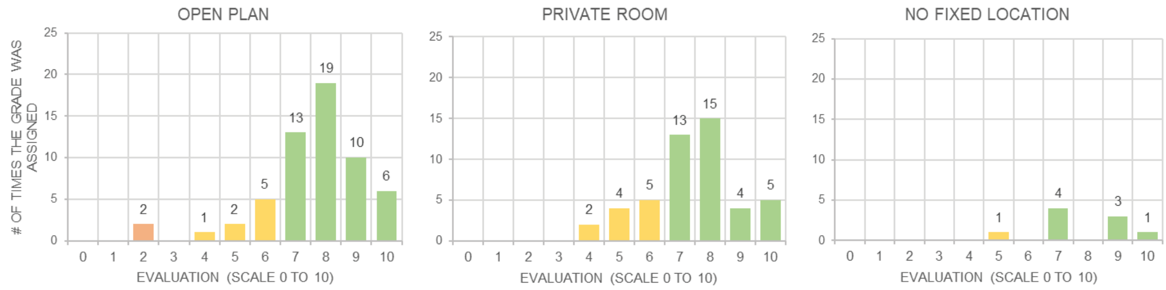


Figure 25 – Score distribution for Overall Comfort evaluation (A21) by layout type.

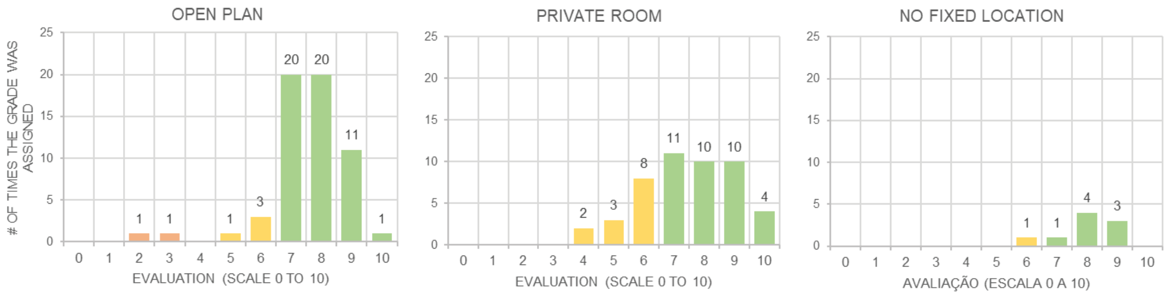


Table 14 – Mean evaluations from Q0 and A21 by layout type.

	n	Mean	Variance	ANOVA: in between groups variation source		
Total sample	115			***f***	**P-value**	***f* critical**
Q0 – IEQ satisfaction						
Open plan	58	7.60	2.88	0.33	0.72	3.08
Private room	48	7.40	2.29			
No fixed location	9	7.78	2.44			
A21 – overall comfort						
Open plan	58	7.53	1.83	0.55	0.58	3.08
Private room	48	7.46	2.42			
No fixed location	9	8.00	1.00			

Figure 26 – Correlation between satisfaction vs. overall comfort scores by layout type.

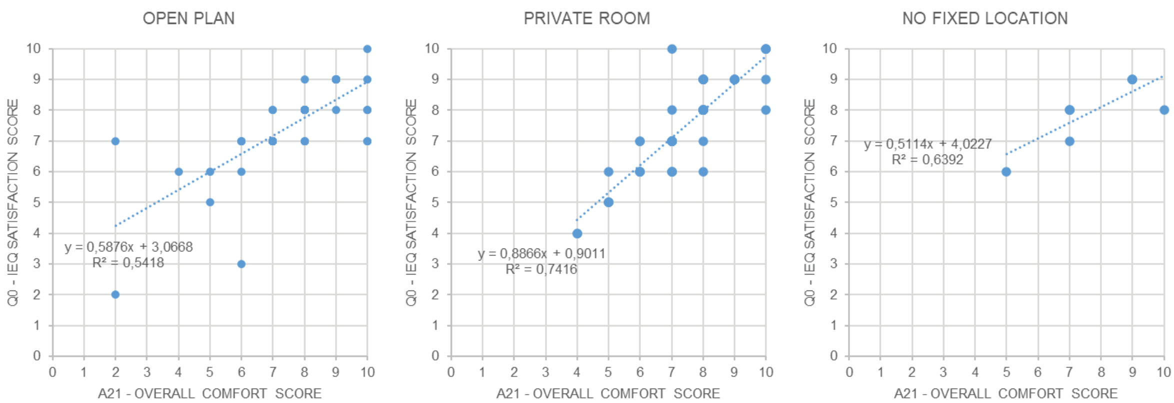


Figure 27 - Time spent at workstation *vs.* satisfaction evaluation by layout type.

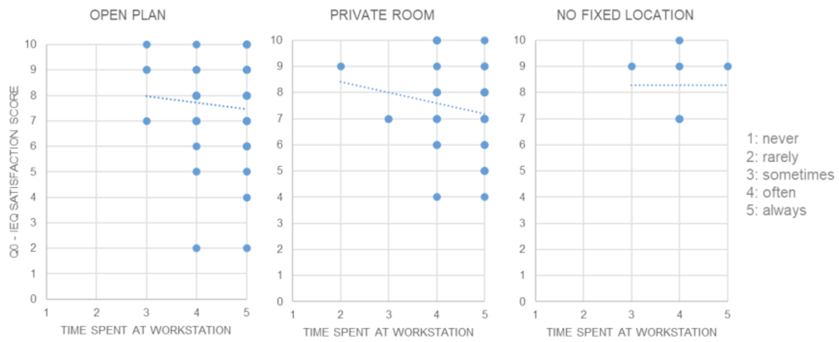
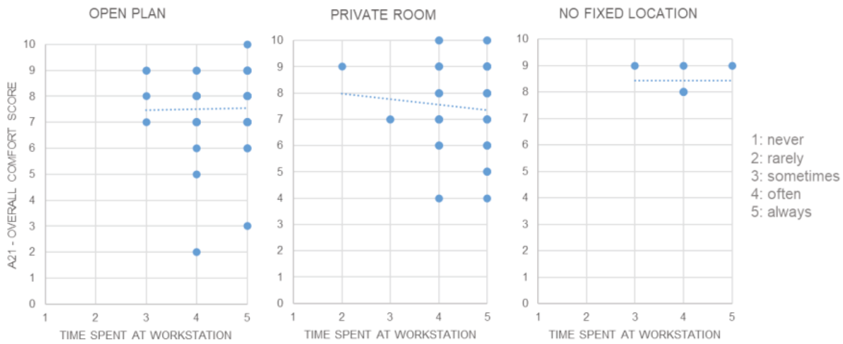


Figure 28 - Time spent at workstation *vs.* overall comfort evaluation by layout type.



Another analysis regarding IEQ satisfaction and overall comfort evaluation was done from the stratification of time spent at workstation in order to verify whether this is indeed a variable that interferes in built environment perception and, therefore, necessary in the questionnaire. From correlation tests presented in graphs from Figure 27 and Figure 28, it is possible to observe that the trend line decreases for score attributed according to the increase of time spent at the workstation for both IEQ satisfaction and overall comfort satisfaction, mainly in private rooms. Overall comfort on open plan layout was the only one that showed a slight increase, while no fixed locations showed no difference. From this observation, reflection was raised on whether there is any causal relation between the two variables. At least two possibilities can be considered. On one hand, if spending less time in the workstation due to use of different rooms for specific activities (meeting rooms, dynamic and focused work areas, etc.) can create a comparative parameter and generate higher expectations, and therefore, a lower evaluation of their own workstation. On the other hand, if it is precisely IEQ dissatisfaction and/or discomfort with their own workstation that leads to spend less time in there. This is a point to be followed on future questionnaire applications, and therefore, the question must be kept since time is parameter that seems to exert influence on user perception, mainly for private rooms.

4.2.3.4 Domains in discomfort

From the hierarchy structure proposed in the questionnaire, it was possible to evaluate IEQ domains with highest levels of discomfort through the number of times its respective detailing group of questions (part II) was triggered, both isolated and combined with others. No discomfort (no domain triggered) was only reached by 8% of total sample. That is, even though 81% of participants attributed 7 or higher scores for satisfaction with the IEQ in question Q0 (as presented in item 4.2.3.3), it was observed that a higher proportion (92%) indicated medium to high frequencies of discomfort with at least one domain of IEQ in part I of the questionnaire. This result can both corroborate with the hypothesis of negative bias generated by the discomfort list causes mentioned previously, as well as with the hypothesis that facing a list of possible situations experienced generates awareness and reflection about the environment and, therefore, indicative of possible problems. It is important to point out, however, that this result can only be evaluated due to the path added for the pilot study, in which even when rating 7 or more on Q0, every participant went through at least part I of the questionnaire. Therefore, this is another point that should be followed up in the next instrument application, as well as raises the need to evaluate whether the "cut score" of Q0 for triggering or not part I should remain 7.

As shown in Figure 29, no discomfort was reached in 7% of open plan layouts and 10% of private rooms, as illustrated by green bars. The most frequent combination of discomfort triggered were the four domains simultaneously (thermal, IAQ, visual and acoustic) for both layout types, along with acoustical discomfort alone in open plan layouts. This domain alone showed in second position, along with the combination of thermal, IAQ, and acoustical for private rooms. Also, it is possible to notice that acoustic comfort showed up on top three positions, either isolated or combined with other domains. Thermal comfort shows up in second place, always combined with another domain. From the foreseen application within the framework, in which is proposed to measure physical environmental conditions in parallel to occupant survey application, the evaluation of combined domains in discomfort can help to understand combined and cross-modal effects of IEQ domains, and provide data needed to consistent investigations from real life experiences.

Figure 29 – Combination of domains in discomfort in open plan and private room layouts.

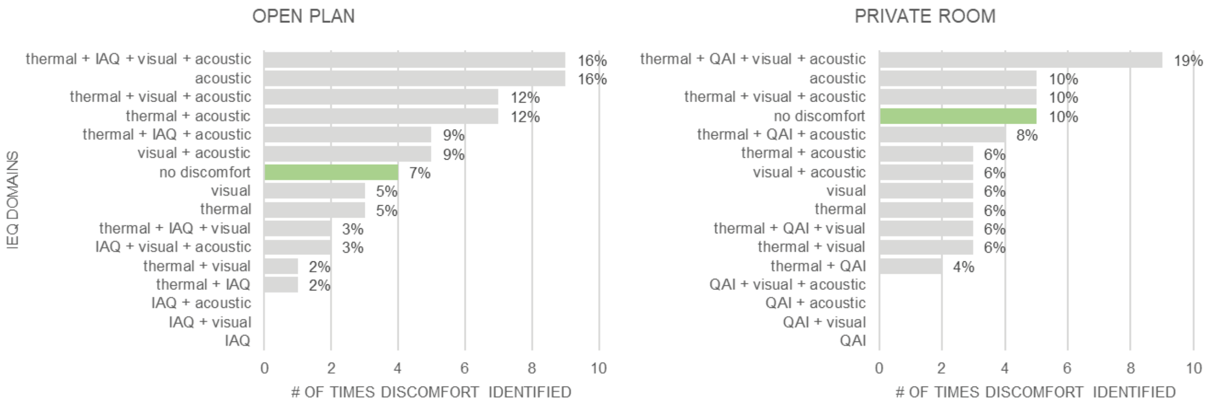
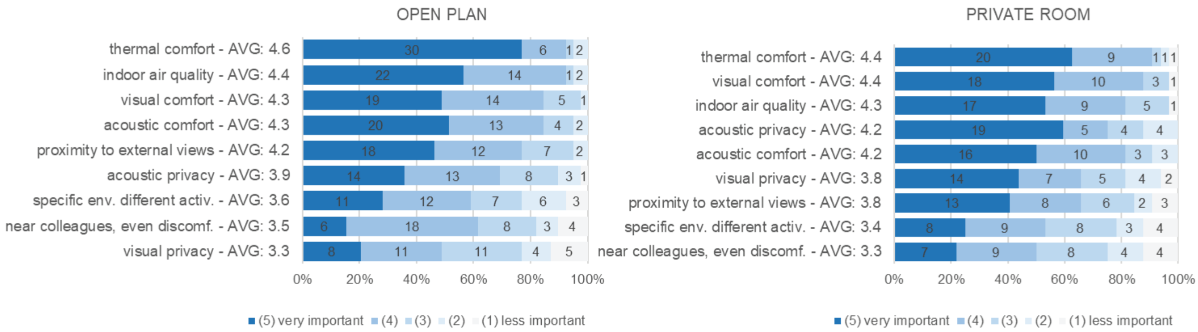


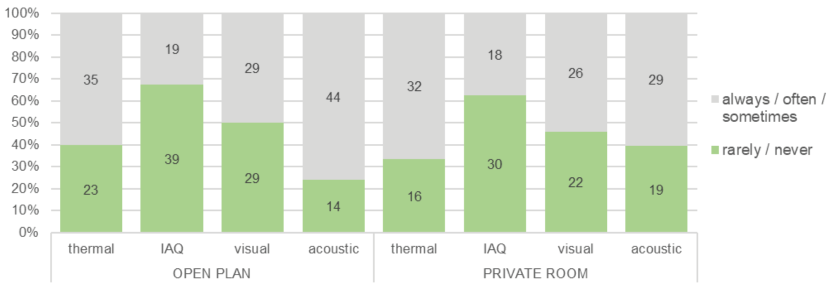
Figure 30 – Order of importance in open plan and private room layouts.



In addition, whenever two or more IEQ domains were triggered in part I, question A26 was added after detailing questions in part II (see map in Figure 18). The purpose of this question was to understand the level of importance of each item in a list that covered IEQ domains (thermal, visual and acoustic comfort, and IAQ), but also unfolding items of the main theme. Items included acoustic and visual privacy, the existence of specific environments for different activities, proximity and /or access to external views, and to be near colleagues, even if uncomfortable. Graphs in Figure 30 present the averages for each item and the frequency of score attribution, with 1 being "*less important*" and 5 being "*very important*". In both layout types, first three positions on level of importance were occupied by comfort and IAQ, tied with acoustic privacy in private rooms. Also, on both layout types thermal comfort ranked first with the highest score, reaching almost 80% of the responses in the open plan layouts as being a very important factor. No other item scored as high as 60% for this type of layout. This observation raised the question of whether the order in which the items were presented could have influenced participants, since thermal comfort was the first item on the list (see APPENDIX B, Table 19). To mitigate this doubt, it is suggested that the items order to be randomized, checking its adherence on the next instrument' versions.

Interesting points can be raised from observation of importance level' rankings. Combination of all four IEQ domains simultaneously achieving the highest frequency of activation (Figure 29) aligns with the ranking of importance presented for both layouts, with similar mean scores amongst them (Figure 30). Furthermore, IAQ was the only domain that was not triggered individually in part I, but always in combination with one or more domains (Figure 29). However, it remained with high mean scores of importance for both layouts (Figure 30). On the other hand, acoustic privacy in open plans ranked fifth in level of importance (Figure 30), even though "noise from colleagues' conversations" was the item with the highest frequencies of discomfort indicated in question [7/7] of part I for all items in all domains (Figure 31). These observations illustrate the possibility of comparison and interpretation of data obtained through the questionnaire that can help in decision making and prevent inaccurate prioritization and sub-optimal resourcing of IEQ factors, complementary to satisfaction model evaluations.

Figure 31 – Identification of discomfort with IEQ domains by layout type.



For analysis of domains isolated, discomfort with acoustic environment was the most triggered domain in open plan layouts, as presented in Figure 31, reaching almost 80% of responses and followed by thermal environment, with 60%. Predominance of discomfort with acoustic and thermal environments aligns with the results presented in Graham; Parkinson; Schiavon (2021) and Lee; Guerin (2009). For private rooms, however, this rank is inverted: the most triggered domain was thermal environment, with almost 70%, and followed by 60% on the acoustic environment. Visual domain had smaller variation between office layout types, with discomfort indicated by around 50% of participants. Indoor air quality was the domain with lowest discomfort rates, with less than 40% for both layout types. Stratification of answers by layout type in this case may be helpful to characterize IEQ domains regarding Kano' model (Basic, Bonus or Proportional factors) differently, according to occupants' expectation. Also, it is suggested the graphs in Figure 29 and Figure 31 to be used as survey indicators, and percentages of discomfort frequency to be followed and compared over time.

4.2.3.5 Discomfort list causes

The complete discomfort causes list was proposed to help identification of critical points of each IEQ domain, in which indication of high frequencies of time in discomfort means points to be investigated and improved in building operation. Furthermore, they can serve as indicators or milestones to be achieved. For instance, eliminate the occurrence of maximum frequency (*always*, illustrated in red bars in Figure 32*)* for each domain; or achieve minimum proportions of responses with low frequencies (*rarely and never*, illustrated in green bars Figure 32).

Figure 32 – Discomfort causes list for IEQ domain by layout types.

From acoustic environment, the main issue identified was noise from colleagues' conversations, with approximately 30% in both layouts, as showed in Figure 32. It is important to notice that all causes on the list were marked *always* at least once on this domain. For the thermal environment, it is observed that higher indications of *always, often* and *sometimes* discomfort frequency due to cold may be justified by the time of year when the pilot study was conducted (cold months), showing a possible recent memory bias. To mitigate this chance, it is suggested the questionnaire to be applied twice a year and obtain user perception regarding both seasons. Managers can follow this observation in part II, by checking comfort votes (A4) and satisfaction rates for summer (A8 and A8a) and winter (A8 and A8b). Also, predominance of never feeling discomfort with most items in private rooms might be related to personal control, which could as well be followed in part II (A5, A6, and A7). As for visual environment, reflection on computer screen was identified more frequently in open plan layouts. Illuminance levels had inverted results, showing insufficient levels in open plants (too dim) and excessive (too bright) in private rooms. These results can also be followed in part II (A11, A13, A17 and A17a), by checking whether the light source causing discomfort is coming from natural or artificial lighting. Indoor air quality showed similar results in both layout types, with discomfort due to dust being slightly critical in private rooms.

4.2.3.6 Influence on behavior and privacy issues

The section related to visual and acoustic privacy was triggered when absence of specific environments for specific activities (focus areas; group activities; meeting rooms) was indicated in question [3/7] from Part I (Table 9). Graphs in Figure 33 shows that acoustic privacy indeed showed the most critical evaluation, especially in open plans; while visual privacy seemed more balanced, especially in private rooms, but still with almost 50% of dissatisfaction. Beyond these figures, analysis from participants comments (further presented in the item 4.2.3.7), privacy proved to be an important matter on IEQ satisfaction, mentioned frequently. Therefore, it is recommended to review the branching structure of the questionnaire for privacy section, expanding its application as a mandatory detailing section on part II.

Influence on behavior section (questions A28 and A29) were only applicable when "no fixed location" was indicated in question [1/7] from Part I (Table 9). The branch condition considered that, in these cases, participants would be free to choose their workstation on a daily basis, and the purpose of the question is precisely to assess whether or which IEQ parameters influence their choice. Graph in Figure 34 shows the frequency of 1 to 5-score ratings obtained for the nine cases of no fixed locations in the pilot study, as well as the averages obtained for each item. Thermal comfort, acoustical comfort, and acoustical privacy were the three items indicated as the most important parameters in defining the workstation; IAQ was in last place. In question A29, more than 50% of the participants indicated that "always" rely on their own preferences when choosing their workstation.

Figure 33 – Privacy evaluation.

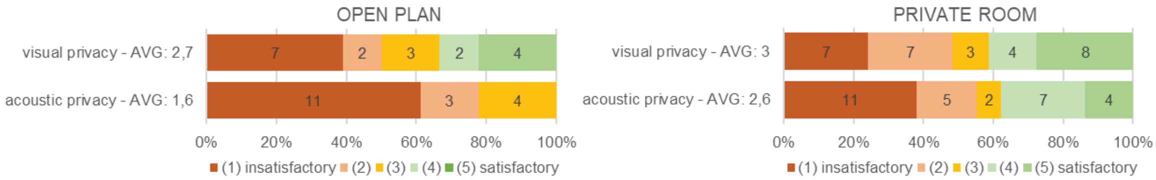
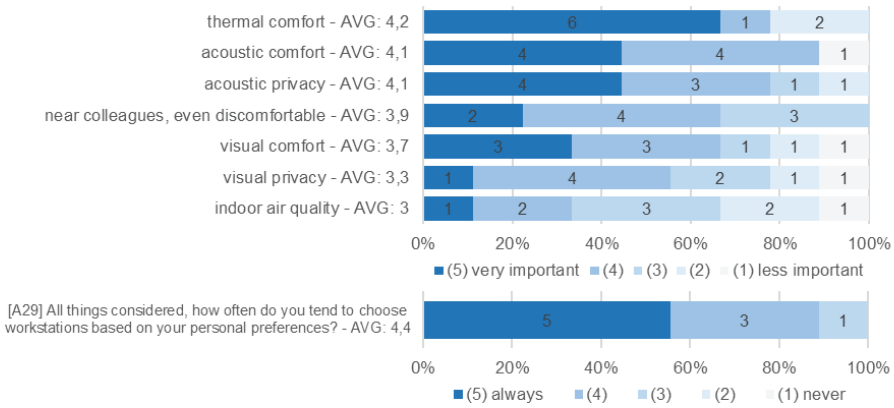


Figure 34 – No fixed locations: IEQ influence on behavior.



Even though pilot study' sample for this type of layout is small, it is interesting to notice that evaluation of IEQ satisfaction (Q0) and overall comfort satisfaction (A21), as presented in Table 14, indicate that this is the layout type that achieves the best average ratings. This configuration is similar to activity-based offices. Engelen *et al.* (2019) review study on whether activity-based working impacts health, work performance and perceptions indicated that research participants consistently rated the physical work environment positively, and that there seems to be a consensus that activity-based work is associated with greater control of where and when they perform their tasks, which can become a challenge to managers. Also, IEQ preferences and workstation choice was addressed in the study by Jahathissa et al. (2020), which collected feedback of comfort-based preference and further clustered occupants and spaces according to preference tendencies. Groups were used to create different feature sets with combinations of environmental and physiological variables, aiming to find comfort preference prediction and suggest workplaces available within the building. This section group can help on providing data for non-fixed location layout types, complementing particularities inherent to this office configuration.

4.2.3.7 Open comments analysis

In the Overall Comfort evaluation section, following question A21 an open-ended question was proposed for participants to freely express any comments regarding their workstation IEQ in question A22. Thirty comments were obtained in the pilot study, corresponding to 26% of participants sample. Beyond IEQ domains, feedbacks regarding architecture in general were also obtained, both positive (2 comments) and negative (4 comments). Comments were categorized according to its content and are fully presented in Table 21 of APPENDIX B.

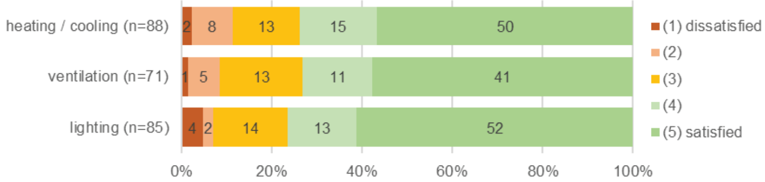
Cold thermal discomfort (both air temperature and air speed, AC setpoint and control) was raised by participants, once again indicating the possible recent memory bias from the cold period of questionnaire application. Visual (mainly glare from natural light), and acoustic (mainly colleagues' conversations) environment issues are aligned with the results from part I, as shown in graphs from Figure 32. It is interesting to note that many comments were followed by possible reasons and sometimes even solutions proposed by the participants themselves. For instance, many recognized that the glare problem was due to their workstation position in relation to the window, and that curtains would be needed at certain times of the day. Same was observed on the issue of disturbance from colleagues' conversations, in which the use of headphones was indicated in most cases to ease the difficulty in concentrating. Participants also exposed issues that indicated difficulty in finding balance among IEQ domains combination on operating building systems and features, which may represent a more complex task to management teams to deal with. For instance, thermal and visual domains showed conflict between direct sun radiation *versus* natural lighting, and thermal gain with glass facades *versus* external views ("*The building structure allows too much sunlight into the work environment. In addition, the temperatures tend to be* *very cold in winter and very hot in summer*”). IAQ was linked to thermal domain mainly due to Covid-19 on opening windows for air renewal *versus* wind speed (“*Thermal discomfort due to cold is happening because of Covid-19 pandemic, since now we must keep the window and door open to ensure air renewal. The fact is that my workstation is located in front of the only opening in the room (door), exactly at the drafty area. There are also large windows in the room, but they are all sealed*”); and also to acoustic, such as external noise and pollution *versus* air renewal (“*Door is always open, with a lot of external noise and air pollution*”).

By going throught the set of open comments for question A22, it becames clear the relevance of having space for qualitative analysis of the comments in parallel to the quantitative measurements, since it allows to know the reasons why occupants are uncomfortable and dissatisfied, in combination with “which” discomfort and “how often” they experience it. These types of insights can be valuable for BPE, as it gets closer to possible problems from the occupants' perspective, either to identify good and bad current practices. Indeed, “survey stories” can extract such feedback, as indicated on Day; O’Brien (2017) study. From previous occupant behavior and energy studies, authors provided a framework in which stories were categorized into five dominant themes. They are social influences, that is, occupants not wanting to affect others and/or culture not being conducive to improve IEQ conditions; economic concerns, as whether they pay for energy or justify behaviors based on costs; misalignment of occupants and operators, where occupants behave in logical and intuitive ways to them, but in contrast to operational intent; lack of control, either real or policy imposed, and also pure discomfort (DAY; O’BRIEN, 2017). Except from economic concerns, all the other themes could be identified from pilot study sample. Such interpretation can be helpful to propose IEQ satisfaction improvemnts, as challenging as they may be.

4.2.3.8 Problem solving evaluation

Problem solving of building systems questions (A24 and A25) are presented in Table 19 from APPENDIX A and are directly linked to Facility Management. Question A24 is designed to evaluate user satisfaction with the speed and efficiency of requests to building operators. Graph in Figure 35 shows that the item with the highest request for adjustments (highest *n* value) is heating and/or cooling system, followed by lighting and ventilation. Amongst participants who requested adjustments, a minimum of 70% indicated high satisfaction rates (4 and 5 scores) for all three systems.

Figure 35 – Question A24: problem solving evaluation.



Complementarily, thirteen participants left comments in question A25, corresponding to 11% of the sample. Comments were evenly split between thermal and visual comfort (5 each), and are fully shown in Table 22 from APPENDIX B. Two comments mentioned aspects related to more than one IEQ domain. A resquest for "*larger and darker blinds to improve direct sunlight*", related to thermal and visual comfort issues, and a situation describing the impact of changing blinds position and AC setings on the indoor air quality ("*even if I ask to close the curtains to avoid reflections on the computer, eventually someone asks to open it because it is a stuffy environment. The same goes for AC temperature and air speed*"). Only one participant used the space to give positive feedback regarding building systems ("*it is a brand new building and we have only been here for a short time, I am quite satisfied with the structure and features*").

As stated on the previous item, feedback from users regarding the system operation is important to understand eventual misalignment of occupants and operators. For instance, one participant stated that had never requested any AC adjustments, saying that "*I usually help myself with coats, scarves and gloves inside my workplace*". Another stated that "*the AC in our office doesn't regulate the thermostat well, and we don't have control over air speed. So, when we turn the equipment on, even though we set it to a higher temperature, the environment becomes uncomfortable due to cold and strong wind*". Both situations can be critical, not only due to comfort issues but because they can also mean energy waste on keeping lower setpoint temperatures, and to provide a space for participants to share such situations must be taken into consideration by facility management teams.

5 CONCLUSION

This research proposed a process-oriented assessment framework for user satisfaction with the workplace regarding IEQ for office buildings, focused on occupancy phase of BPE. It consists of a modular-type structure intended to create a clear and gradual process of data collection for problem identification, implementation of necessary corrective actions, and further follow up for reevaluation. This modular structure answers to specific aim (i) on identifying recommendations for IEQ and user satisfaction enhancement by providing a better understanding of building specific particularities and supporting decision-making process. Within the mentioned framework context, this research also proposed a survey instrument to assess occupants' perception of IEQ-related issues, designed to be adopted on the *Standard* stage and to complement the building diagnosis in conjunction with physical measurements. The longitudinal questionnaire was developed from comparative analysis of reference user satisfaction surveys selected from international literature review. To reduce the questionnaire extent and yet address all relevant topics, as pursued by specific aim (ii) in order to increase engagement rates, the instrument' main structure was divided into two hierarchical parts. Part I worked as a filter for the detailing questions in part II, by dismissing participants who did not indicate discomfort; and whenever discomfort was detected, part II was triggered allowing to collect more information. Definition of question items and measurements scales were proposed, and the on-line form and interface were also set for testing. Tests were carried to find evidence of both content validity (review of researchers and industry experts of each IEQ domain to assess the addressed content on whether all variables inherent to each domain were contemplated) and face validity (subjective evaluation of proposed questions and their respective items to determine whether they seem logical, clear, and appropriate to the concepts studied). The final questionnaire version was reviewed based on the comments and observations indicated at the end of this process. Finally, a wider application was conducted with office employees in general on a pilot study to simulate real application. Building measurements were not collected for instrument testing.

Participants evaluation of the questionnaire in the pilot study application showed suitability of the instrument to measure IEQ satisfaction with their work environment, answering to specific aim (iii). Instrument's adequacy to evaluate satisfaction with IEQ obtained an average score of 4.75 out of 5 points. Organization, content comprehension, readability, clarity, and objectivity aspects also reached high evaluation scores, with minimum average of 4.55 out of 5 points. Further instrument' reviews should consider counterbalancing objectivity and clarity, focusing on semantic aspects as well as visual cues presented, as pointed by participants in open comments section.

Exploring data from pilot study application, performance indicators were suggested as well as meaningful findings related to IEQ occupant satisfaction were identified as possible complementary results to be extracted from instrument' application. Those outcomes can assist understanding of building specific particularities and support decision-making process by helping to identify possible recommendations for IEQ and user satisfaction enhancement, answering to specific aim (iv). Regarding the instrument structure, hypotheses were raised regarding the IEQ discomfort list in part I. The first was that, by facing the list of possible situations experienced on a work routine, would generate awareness about the IEQ matter in the work environment in participants and thus, would also bring indications of possible problems with these aspects, previously unnoticed. Indeed, indications of this awareness can be observed from the difference between no discomfort rates (no domain triggered), reached only by 8% of total sample, versus 81% of participants attributing 7 or higher scores for satisfaction with the IEQ in question Q0. That is, a higher proportion (92%) indicated medium to high frequencies of discomfort with at least one domain of IEQ in part I of the questionnaire, even after rating high grades in Q0. However, it also led to the second hypotheses, that the discomfort list could act as negative bias towards lower overall comfort scores, since it describes uncomfortable situations asking participants to attribute a frequency of experience of those issues in their work routine. No evidence of negative bias was observed from the pilot study sample, since correlation trends between IEQ satisfaction (Q0) and Overall Comfort satisfaction (A21) were always positive. Nevertheless, further studies must follow up this outcome in order to check and avoid research biases.

Regarding stratified analysis from proposition in Part I by layout type (question [1/7]) and time spent in the workstation (question [3/7]), stratification showed different outcomes among the evaluated samples. For instance, the proportion of domains in discomfort (both combined and individually) and no frequent discomfort, as well as the level of importance of each aspect of IEQ varied for different layout types. Considering a real experience of questionnaire application, although spatial office configuration can be obtained from available material in Preset Data, questionnaire is anonymous and, therefore, it would not be possible to group the answers from layouts with the same characteristics. In this matter, results obtained in the pilot study justify keeping the question [1/7] in Part I, as it can help to identify specific critical points and any eventual suggestions of solutions by building and office managers. Same applies to the time spent at the workstation, since results showed a trend of decreasing IEQ Satisfaction and Overall Comfort score attributed according to the increase of time spent at the workstation, mainly in private rooms. Instrument application in a case study, with due follow-up of the other variables and building measurements should focus on this aspect.

Regarding possible indicators from occupant survey, six indexes were proposed: IEQ Satisfaction Score (Q0) and Overall Comfort Satisfaction Score (A21) as major outcomes for the entire office; and Overall Thermal Satisfaction (A8); Overall IAQ Satisfaction (A10); Overall Visual Satisfaction (A17); Overall Acoustic Satisfaction (A20) for specific IEQ domains evaluations. A Facility Management Score (A24) is also proposed. Beyond indexes themselves, the evaluation of combined domains in discomfort can help to understand combined and cross-modal effects of IEQ domains, and provide data needed to consistent investigations from real life experiences. On open questions, participants exposed issues that indicated difficulty in finding balance among IEQ domains combination on operating building systems and features, which may represent a more complex task to management teams to deal with. These types of insights can be valuable for BPE, as it gets closer to possible problems from the occupants' perspective, either to identify good and bad current practices.

Critical analysis of pilot study results also raised other major instrument' reviews. Concerns regarding privacy issues were raised from results obtained on level of importance of each IEQ parameter, mainly on acoustic privacy. Since privacy assessment was only triggered to participants who indicated to work on offices that do not have specific environments for determined activities (meeting rooms, focus and/or group activities), results were very restricted to be compared to question A26, which may lead to misinterpretation. Therefore, it is recommended to review the branching structure of the questionnaire for privacy section, expanding its application as a mandatory detailing section on part II. Regarding question elements, scale adjustment should be carefully weighted, considering setting all questions to be evaluated on a 5-point scale. This concern is raised since, despite 81% of participants scored 7 or higher for their workplace IEQ satisfaction evaluation (Q0), low percentages of participants indicated no discomfort (no domain triggered for detailing) in Part I. These results can be interpreted as a conflicting outcome. Also, score distribution on questions Q0 and A21, which were concentrated on 4 to 10, can be evidence that broader scales such as 0 to 10 might be inadequate for this type of evaluation. Possible reasons can range from participants' difficulty to differentiate between values until psychosocial aspects. Mentioned issues also relate to instrument' first main branch structure, the one that triggers Part I of domain identification from the occupational climate survey (Q0). Consideration about the "cut score" of Q0 should be taken, perhaps increasing from 7 to a higher score, in order to give more participants an opportunity to share their opinion and therefore provide a comprehensive diagnostic. Regarding question items, awareness around habit bias was raised from pilot study results. To mitigate this doubt, it is suggested that the items order to be randomized, checking its adherence on the next instrument' versions. Higher frequencies of cold thermal discomfort obtained in the pilot study may be indicative of the needed biannual frequency (summer and winter or hot and cold months) for the instrument to be applied, in order to avoid recent memory bias, which should be foreseen within framework guidelines. The follow-up branching for this part configuration of question A8 could be pre-defined according to the period of application (setting A8a or A8b), referring only to the period in question.

This research proposed a survey instrument designed to assess occupants' perception of IEQ-related issues in the work environment and tested its application in a pilot study with the targeted population to evaluate it. Results showed instrument adequacy to assess satisfaction with IEQ, beyond bringing meaningful outcomes for a better understanding of building specific particularities and supporting decision-making process in the occupancy phase. However, limitations that restrict generalization of the results obtained were identified. These limitations are presented below, as well as recommendations for future studies.

5.1 STUDY LIMITATIONS

The COVID-19 pandemic has kept a large part of office employees away from workplaces due to health and safety impositions. By one hand, this event raised the awareness about IEQ in the work environments we have been building and occupying, increasing the relevance to the subject of user satisfaction with such places. However, instability derived from such impositions, ongoing at the time of this research development, also restricted the possibility of conducting field studies in which physical environmental conditions could be measured and monitored. Therefore, it prevented one of the main goals of the proposed framework from being tested: the combination of physical measurements with subjective user data, as recommended on BPE studies. Monitoring such data could enhance instrument testing processes, since physical measurements would serve as a reality check of occupants' subjective perception, assisting results interpretation.

Another limitation of this study consists in the extension of the proposed framework, whose structure requires application in a long-term case study. Therefore, within the scope of this research, only one part of the entire proposed assessment method could be tested - the longitudinal questionnaire. Although critical analysis of testing this instrument individually, as presented in this study, brings important topics for improvement, its application in a case study is necessary to evaluate its adequacy on a real-world context, subject to the circumstances and variances inherent to the occupation phase.

Regarding the tests carried, it is acknowledged that validation processes require wider instrument applications, which could not be achieved within this research scope, as previously mentioned. The effort of testing the instrument in a pilot study, even on a reduced sample size, was to provide a first contact with general targeted participants (office employees), gathering preliminary evidence of content and face validity considering the objectives of the delimited framework. Even though the results obtained showed suitability of the instrument to measure IEQ satisfaction with the work environment, appropriate validity and reliability tests should be conducted in future instrument applications in order to consolidate it as a consistent occupant survey that can contribute to identify the perception of occupants on IEQ-related issues and offer a comprehensive building diagnosis.

5.2 FUTURE STUDIES

Future study recommendations include:

(i) Broad application of the proposed instrument in a real workplace context, while monitoring physical environmental variables, in order to refine discussions and improve outcomes brought in this study, after adjustments proposed in this critical analysis.

(ii) Evaluation of the general and specific performance indicators proposed to represent user perception with wok environment IEQ, in order to consolidate a comprehensive building diagnosis.

(iii) Development of the occupant satisfaction survey suggested to be adopted in the Complete and Advanced modules, based on instantaneous user approaches, following the trend identified in the international literature review.

(iv) Follow up of long-term case studies in order to apply the proposed framework and test its efficiency as a method for evaluating user satisfaction with IEQ aligned to the concept of BPE, seeking for a better understanding of building specific particularities and supporting decision-making process in the occupancy phase.

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APPENDIX A – LONGITUDINAL QUESTIONNAIRE PART II. DETAILING QUESTIONS

Table 15 – Thermal Comfort.

#	Question	Items	
A1	Please indicate which of the following items are present in your workplace: 1. Air conditioner: cooling 2. Air conditioner: heating 3. Fans: ceiling and/or wall fans 4. Fans: portable, table and/or individual	a) yes b) no	
	At your workstation, how do you describe or rate...		
A2	...the thermal environment: 1. during summer and/or hot months? 2. during winter and/or cold months?	(1) hot (5) cold	
A3	...the air movement: 1. during summer and/or hot months? 2. during winter and/or cold months?	(1) windy (5) stuffy	
A4	...the thermal environment: 1. during summer and/or hot months? 2. during winter and/or cold months?	(1) uncomfortable (5) comfortable	
	Regarding the existing controls in your workplace, how do you rate the level of control you have...		
A5	over heating and/or cooling?	*[illustrations with brief descriptions]* a) No control: AC thermostat and wind speed and direction is not available b) Some control: cannot control AC thermostat, only air speed and direction c) Some control: cannot control AC wind speed and direction, only thermostat d) Full control: I change AC thermostat and wind speed and direction whenever I feel uncomfortable with indoor temperature e) Some control: I can make changes in temperature as I prefer, but I have to call and/or contact the person in charge of the system f) Some control: all colleagues give their opinion and we reach an agreement g) No control: the decision to turn the air conditioning on or off is not mine	
A6	over natural ventilation?	*[illustrations with brief descriptions]* a) No control: windows are not operable and are always closed b) No control: windows are operable, but it is mandatory to be always closed c) Full control: I open/close the window closest to my workstation whenever I feel uncomfortable with the temperature, movement and/or speed of the air f) Some control: all colleagues give their opinion and we come to an agreement g) No control: the decision to open or close the windows is not mine	
A7	over the fans?	*[illustrations with brief descriptions]* a) No control: cannot control the fans (turn on or off, change wind direction and intensity) b) Full control: I turn the fan(s) closest to my workstation on and off whenever I feel uncomfortable c) Some control: all colleagues give their opinion and we come to an agreement d) No control: the decision of turning the fans on or off is not mine	
A8	All things considered, how satisfied are you with the thermal environment at your workstation? 1. during summer and/or hot months? 2. during winter and/or cold months?	(1) dissatisfied (5) satisfied	Thermal Comfort score

#	Question	Items
A8a A8b	We have a low score for [hot / cold] months... So, to be sure, please indicate the reasons why you are dissatisfied with the thermal environment during this period.	*[check boxes]* a) I feel hot discomfort b) I feel cold discomfort c) I feel discomfort because there is too much wind d) I feel discomfort because there is not enough wind e) Direct sun disturbs me f) There are nearby surfaces (floors, walls, etc.) that are too hot or too cold g) I feel hot or cold discomfort in specific parts of my body (hands, feet, neck, head, etc.) h) I feel discomfort due to draft from air-conditioning i) I feel discomfort due to draft from fan(s) j) I feel discomfort due to draft coming from window(s) l) I feel discomfort because I cannot control the windows according to my preference m) I feel discomfort because I cannot control AC temperature according to my preference n) Other, please specify:

Table 16 – Indoor Air Quality.

#	Question	Items
A9	Regarding the indoor air quality in your workstation, how often do you identify any of the following items or symptoms? 1. Ambient smells and/or odors 2. Feeling fatigued and/or sleepy 3. Dryness in the eyes, nose and/or hands 4. Skin irritations and/or allergies	a) daily, most of the time b) daily, for a few hours c) occasionally, for a few hours d) rarely, for a few hours e) never
A10	All things considered, how satisfied are you with the indoor air quality at your workstation?	(1) dissatisfied (5) satisfied
A10 a	We have a low score for air quality... So, to be sure, please indicate the reasons why you are dissatisfied.	*[check boxes]* a) smells and odors b) stuffy environment c) indoor air too dry d) indoor air too humid e) dust or products that cause irritation or allergies f) Other, please specify:

Table 17 – Visual Comfort.

#	Question	Items
	At your workstation, how would you describe or rate...	
A11	...the availability of artificial lighting (lamps and fixtures)?	(1) low (5) high
A12	...glare occurrence by artificial lighting?	(1) recurrent (5) inexistent
A13	...availability of natural lighting (sunlight and sky)? 1. during summer 2. during winter 3. during mornings 4. during afternoons	(1) low (5) high
A14	...glare occurrence by natural lighting? 1. during summer 2. during winter 3. during mornings 4. during afternoons	(1) recurrent (5) inexistent
	Regarding the existing controls in your workplace, how do you rate the level of control you have...	
A15	...over artificial lighting?	a) No control: switches are not located in the room b) Some control: the switches are too far away from my workstation c) No control: all light fixtures are operated by a single switch (all on or all off) d) Some control: I can choose to turn on the lights according to the available natural light e) Total control: I turn the lights on or off whenever I feel uncomfortable with artificial lighting

#	Question	Items
		f) Some control: all colleagues give their opinion and we come to an agreement g) No control: the decision to turn the lights on or off is not mine
A16	...over natural lighting?	a) No control: there are no shading elements (curtains or blinds) to adjust natural lighting b) Full control: I open and close the curtain closest to my workstation whenever I feel uncomfortable with natural lighting c) Full control: I open and close the curtain closest to my workstation whenever I feel uncomfortable with direct sunlight d) Some control: all colleagues give their opinion and we come to an agreement e) No control: the decision to open or close the curtains is not mine
A17	All things considered, how satisfied are you with visual environment at your workstation?	(1) dissatisfied (5) satisfied
A17 a	We have a low score for visual environment... So, to be sure, please indicate the reasons why you are dissatisfied.	*[check boxes]* a) I feel discomfort with a too bright room b) I feel discomfort with a too dim room c) I feel discomfort with glare d) I feel discomfort with reflections on my computer screen e) I feel discomfort with flickering lights f) I feel discomfort because I cannot differentiate objects (high and/or low contrast) g) I feel discomfort because I cannot control shading elements (curtains or brises) h) I feel discomfort because I cannot control lamps and fixtures i) Other, please specify:

Table 18 – Acoustic Comfort.

#	Question	Items
	At your workstation, how would you describe or rate...	
A18	1. Noise from colleagues: conversations that I can understand what is said 2. Noise from colleagues: background conversations that I can't understand what is said 3. Noise from colleagues: keyboards, footsteps, opening and closing drawers, etc. 4. Noise from the building: air-conditioning 5. Noise from the building: other equipment 6. Noise from the building: telephones ringing 7. Noise from surroundings: external noise, coming from outside	(1) not disturbing (5) disturbing
	Regarding the existing controls in your workplace, how do you rate the level of control you have.	
A19	...over external noises?	a) Total control: I open and close the nearest window to my workstation whenever I feel uncomfortable with external noises b) No control: windows are not operable and are always closed c) No control: windows are operable, but it is mandatory to be always closed d) Some control: all colleagues give their opinion and we come to an agreement e) No control: the decision to open or close the window is not mine
A20	All things considered, how satisfied are you with acoustic environment at your workstation?	(1) dissatisfied (5) satisfied
A20 a	We have a low score for acoustic environment... So, to be sure, please indicate the reasons why you are dissatisfied.	*[check boxes]* a) I feel discomfort with conversations from colleagues b) I feel discomfort with air conditioning noise c) I feel discomfort with equipment noise d) I feel discomfort with telephones ringing noise e) I feel discomfort with external noise, coming from outside f) there is not a suitable place to have a private conversation with colleagues g) there is not a suitable place to make a phone or video call

#	Question	Items
		h) Other, please specify:

Table 19 - Complementary questions.

#	Question	Items
	OVERALL COMFORT	
A21	All things considered, please indicate your level of satisfaction with your workstation overall comfort.	Scale 0 to 10
A22	Please feel free to add any comments you may have regarding the Indoor Environmental Quality on your workstation.	*[open-ended question]*
	PERSONAL CONTROL	
A23	How satisfied are you with the control availability of the following items to adapt your workstation to meet your preferences? 1. air conditioners and/or heaters 2. fans 3. opening or closing windows 4.opening or closing curtains 5. turning lights on or off	(1) dissatisfied (5) satisfied (6) this item does not exist in my office
	PROBLEM SOLVING	
A24	When requesting any adjustments on the following systems to suit your preferences, how satisfied were you with the speed and efficiency of the response to your request? 1. heating and/or cooling: e.g., raising or lowering temperature thermostat 2. ventilation: e.g., increasing or reducing air speed and/or direction 3. lighting: e.g., changing, turning on or off lamps; opening or closing shading	(1) dissatisfied (5) satisfied (6) never requested adjustments
A25	Would you like to share an occasion when adjustments were necessary to improve your satisfaction with your workstation?	*[open-ended question]*
	HIERARCHY OF IMPORTANCE	
A26	Considering the current physical environment of your workplace, could you indicate the level of importance of the following factors for you to perform your daily activities? 1. thermal comfort 2. indoor air quality 3. visual comfort 4. acoustic comfort 5. visual privacy 6. acoustic privacy 7. proximity to colleagues even if not entirely comfortable	(1) less important (5) very important
	PRIVACY	
A27	How would you rate or describe your workstation regarding: 1. acoustic privacy (not being heard by others)? 2. visual privacy (not being seen by others)?	(1) unsatisfactory (5) satisfactory
	INFLUENCE ON BEHAVIOR	
A28	Which of the following factors are most important when choosing your workstation? 1. thermal comfort 2. indoor air quality 3. visual comfort 4. acoustic comfort 5. specific rooms for different activities 6. proximity and/or access to external views 7. visual privacy 8. acoustic privacy 9. proximity to colleagues even if not entirely comfortable	(1) less important (5) very important
A29	All things considered, how often do you tend to choose workstations based on your personal preferences?	(1) never (5) always

Table 20 - Questionnaire evaluation questions.

Question	Items
How do you evaluate the content of this questionnaire regarding: a) Organization b) Objectivity c) Clarity d) Readability e) Content comprehension	(1) Inconsistent (2) (3) (4) (5) Consistent
In your opinion, are the subjects covered adequate to assess your satisfaction with the Indoor Environmental Quality in your work environment?	(1) Inadequate (2) (3) (4) (5) Adequate
Please feel free to leave suggestions that may contribute to the improvement of this survey instrument.	[open ended]

APPENDIX B – PILOT STUDY OPEN COMMENTS

Table 21 – Question A22 open comments and categorization.

IEQ domain	Comment transcription
Thermal environment	
Air temperature	*Greater discomfort due to cold when colleagues did not agree on the air conditioning.*
	Although the environment has AC (for cooling), during cold days the room is extremely uncomfortable.
	Thermal discomfort during the summer.
	Air conditioning is at everyone's discretion, but the air vent is in front of me and I usually have to change its direction because it gets too cold.
	As for the thermal quality, the building is located by the sea and gets very cold.
	Mornings are unbearably cold; afternoons are pleasant. I'm going to let off a firework when winter is over.
	I am positioned below the AC, where it is often cold and I don't have 100% control over the temperature.
Air speed	*The wind from the AC comes straight at me, but if I raise the temperature, it gets hot for those in other parts of the room. We can't change the wind direction.*
	Our office has an external view, including views from my workstation, but because we are in a ground floor of an office building, we have limited natural ventilation and, at some times of the year, relatively high air humidity.
	No privacy, sun on hot days and wind on cold days.
	The main cause of heat discomfort is when the window is opened to ensure air quality, but the wind comes in through the window and causes neck discomfort.
Visual environment	
Availability of artificial lighting	*It is very personal, but in the matter of lighting, my work preference is for less direct lighting.*
Availability of natural lighting	*I would improve the lighting, window glasses have with very dark film.*
Glare	*The morning sun cause a little glare and reflect on the computer screen, but it is nice to warm up in the winter.*
	My desk is in a position with my back to the window, which is very reflective on the computer screen - I need to put up a curtain...
	Positioned with my back to the window, which interferes with the external light reflection on the computer.
External views	*My office has no external view, the room faces a high wall, which bothers me a lot.*
Positive feedback	*Visually comfortable environment.*
Thermal and Visual environments	
Direct sun / sunlight	*The building structure allows too much sunlight into the work environment. In addition, the temperature tend to be very cold in winter and very hot in summer.*
	As some people don't like to open the window because of the wind and sun (late afternoon), they close the window and it gets darker because of the window film.
	Glass external windows. Good for visibility, sunlight, but bad for not having enough openings to ventilate the room in question. Also, in the heat they make the environment hot (even though the sun doesn't hit directly), but this heat discomfort is mainly due to the lack of air conditioning, not to the glass itself.
Thermal and IAQ environments	
Air speed / air renovation	*Thermal discomfort due to cold is happening because of Covid-19 pandemic, since now we must keep the window and door open to ensure air renewal. The fact is that my workstation is located in front of the only air opening in the room (door), exactly at the drafty area. There are also large windows in the room, but they are all sealed.*
Acoustic environment	
Colleagues conversations	*There is no acoustic treatment in the room, and because it is an open plan, conversations are very noisy and sometimes unintelligible.*
	I think that the acoustic comfort for an "open space" depends a lot on the culture of the company in respecting the colleagues, speaking low and in the environment as a whole. In the office where I work, which is an open plan, they decreased the acoustics problem by providing us better headphones that pick up only your voice and discard the background noise. It has improved a little, but the loud sound in the office is still something that bothers me a lot. For this and other reasons, I prefer remote work.
	The glass partitions lets a little sound through, allowing a certain discomfort sometimes.
	Today the biggest discomfort is the conversations of colleagues in moments of concentration. The solution I found was to use headphones.
	I really like my workstation. I understand that it is larger than that of other employees, however. When it comes to noise, it is true that conversations between other co-workers affect concentration. Because of this, last week we relocated some people's workplaces in an attempt to bring people from similar areas together. This way we were able to reduce the problem. In addition, almost everyone uses headphones during work, especially at times when there is a need for greater focus and concentration.
	We are four women in our sector, separated from the others by low partitions. We get along well, we are quiet and focused, but the people in the other sectors talk very loudly

IEQ domain	Comment transcription
	(especially the men, with all due respect), and sometimes it becomes difficult to concentrate.
	I work in a room with many people, noises interfere with concentration and video calls. We don't always have meeting rooms available.
Noise from phones ringing	*The phone ringing all the time also gets in the way - mine never rings, but in the neighboring sectors it rings all the time.*
Privacy	*The partitions do not provide any acoustic privacy.*
	No acoustic privacy (talking on the phone without colleagues hearing).
	The main problem I have is acoustic isolation. Mainly related to needing to participate in meetings and having noises and conversations in the background. Otherwise, I find my workstation very good, with thermal comfort, lighting and ergonomics OK.
	The acoustics of the building bother me. We can hear conversations from other rooms. We practically always work with the windows closed to prevent others from hearing what we are saying.
	Improvement needed in acoustics, it is a fairly large room and 6 people work on it. There is a lot of talking and lack of privacy which hinders concentration in general.
	There are rotating booths if you need silence, but the idea is to stay together with everyone because our work arrangement is hybrid, we go to the office to interact.
IAQ	
	For the indoor air quality, we have a file in our room that makes the air very bad.
Acoustic and IAQ environments	
External noise / pollution	*Door is always open, with a lot of external noise and air pollution.*
	Due to Covid-19, the external noise and discomfort by strong winds on cold days are more recurrent. When the environment is full, I prefer to leave the closest window open.
Architecture / environment in general	
Negative feedback	*I miss open spaces, outdoors, with more contact with nature and sunlight. Also a more personalized, cozier and less cold/practical/homogeneous architecture.*
	More space.
Positive feedback	*I like my work environment, but I believe it can be improved.*
	The working area is very good, I have sun from the window, but I can control the intensity using the curtains. I have access all the time with the window openings and can control the speed and intensity of the wind.
	It is a good work environment, in which we can control temperature, sound and light.
	The side wall (south facade) is all glass with a good view and air flow.

Table 22 - Question A25 open comments and categorization.

IEQ domain	Comment transcription
Thermal comfort	
Air temperature: cooling setpoint	*The air conditioner in our office doesn't regulate the thermostat well, and we don't have control over air speed. So, when we turn the equipment on, even though we set it to a higher temperature, the environment becomes uncomfortable due to cold and strong wind. Some colleagues are more impacted than others because of their location in the office: the closer to the window, the more comfortable the work environment is because it is cooler and less windy.*
Air movement: fans	*Change the fan location so that the air flow does not get paper sheets flying around!*
Air movement: window control	*I only ask to control window opening to reduce wind intensity.*
System failure	*There have been cases on hot days when the cooling system was not working, but it was solved.*
Thermal discomfort / behavior: clo insulation	*It never happened, I usually help myself with coats, scarves and gloves inside my workplace.*
Visual comfort	
Availability of artificial lighting	*Increase the amount of lighting, since at night, without natural lighting, the environment is dark.*
Availability of natural lighting	*A few years ago, the blinds were removed from my room for maintenance and not returned, so I had to move. In the new place, I don't have problems with insolation, but in the previous place, without the blinds, I did. Now I am further away from windows and without access to natural lighting, using artificial lighting whenever I use my workstation.*
Glare by natural lighting	*One of the company's teams is budgeting for the purchase of blinds because our office is exposed to too much sunlight and it hinders monitor viewing.*

	There is a period in the late afternoon when the sunlight is right in my eyes and we have no blinds.
General management	*Burnt light bulbs above my desk.*
Thermal and Visual comfort	
Direct sun / sunlight	*Larger and darker blinds to improve direct sunlight.*
Thermal, Visual comfort and IAQ	
Shading / AC control	*Even if I ask to close the curtains to avoid reflections on the computer, eventually someone asks to open it because it is a stuffy environment. The same goes for AC temperature and air speed.*

ANNEX A – Reference occupant-centric performance indicators

Table 1 - Selected KPIs from IEQ and comfort: definition, resolution, normalization and quatifiability

	KPI Characteristics					Input Data Resolution			Normalization Factors				Quantifiability via Measurements: sensor, meters and/or required devices														Performance Goal	
Domain	KPI	Definition	Occupant object	Value type	Dimensional	Temporal	Spatial	Occupancy	Temporal	Spatial	Occupant	Weather	N.A.	Occupancy	Occupant count	Illuminance	Temperature	Humidity	Air velocity	Radiant temperature	Co2 concentration	Tvoc	Particle matter	Decibel sound level	Timer	Measurement / calculation effort	Resources	IEQ
VISUAL	1. Spatial Daylight Autonomy (sDA)	The percentage of time that daylight levels are above a specified target illuminance within a physical space.	n.a.	single	no	annual	zone	n.a.	n.a.	n.a.	n.a.	n.a.				x										medium	energy	COMFORT
VISUAL	2. Annual Sunlight Exposure (ASE)	The percentage of floor area that receives at least 1,000 lux for at least 250 occupied hours per year.	n.a.	single	no	annual	zone	n.a.	hours	n.a.	occupant count	n.a.				x										medium	n.a.	COMFORT
VISUAL	3. Useful Daylight Illuminance	A daylight availability metric that corresponds to the percentage of the occupied time when a target range of illuminances at a point in a space is met by daylight.	occupant group	single	no	n.a.	zone	presence	hours	n.a.	occupant count	n.a.				x										medium	energy	COMFORT
VISUAL	4. Workplane Illuminance	The illuminance level of a horizontal workplane.	individual person	single	yes	n.a.	workplane	n.a.	n.a.	n.a.	n.a.	n.a.				x										low	energy	COMFORT

	KPI Characteristics					Input Data Resolution		Normalization Factors					Quantifiability via Measurements: sensor, meters and/or required devices														Performance Goal	
Domain	KPI	Definition	Occupant object	Value type	Dimensional	Temporal	Spatial	Occupancy	Temporal	Spatial	Occupant	Weather	N.A.	Occupancy	Occupant count	Illuminance	Temperature	Humidity	Air velocity	Radiant temperature	Co2 concentration	Tvoc	Particle matter	Decibel sound level	Timer	Measurement / calculation effort	Resources	IEQ
VISUAL	5. View Type	Total number of rays that hit each type of outdoor view element: sky, landmarks, buildings, landscape, and ground.	individual person	single	yes	hourly	single point	n.a.	n.a.	n.a.	n.a.	n.a.	x													very high	n.a.	WELL BEING
THERMAL	6. Predicted Mean Vote (PMV) & Predicted Percentage of Dissatisfied (PPD) model	A model to quantify thermal comfort for a group of occupants with a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation.	occupant group	single or serial	no	n.a.	zone	n.a.	n.a.	n.a.	n.a.	n.a.					x	x	x							very high	n.a.	COMFORT
THERMAL	7. Average PPD	The average PPD over occupied hours during a time period.	occupant group	single	no	hourly	zone	presence	n.a.	n.a.	n.a.	n.a.					x	x	x							very high	n.a.	COMFORT
THERMAL	8. POR [PMV]	Percentage of time outside the comfort PMV range.	occupant group	single	no	percent of time	n.a.	presence	time duration	zone	n.a.	n.a.					x	x	x						x	very high	n.a.	COMFORT
THERMAL	9. Degree-Hour Criterion (DHC)	Sum of occupied hours multiplied by actual operative temperature exceeding the corresponding comfort range.	occupant group	single	yes	hourly	zone	presence	n.a.	n.a.	n.a.	n.a.		x			x	x	x	x						very high	n.a.	COMFORT

KPI Characteristics						Input Data Resolution			Normalization Factors				Quantifiability via Measurements: sensor, meters and/or required devices														Performance Goal	
Domain	KPI	Definition	Occupant object	Value type	Dimensional	Temporal	Spatial	Occupancy	Temporal	Spatial	Occupant	Weather	N.A.	Occupancy	Occupant count	Illuminance	Temperature	Humidity	Air velocity	Radiant temperature	Co2 concentration	Tvoc	Particle matter	Decibel sound level	Timer	Measurement / calculation effort	Resources	IEQ
THERMAL	10. Degree-Occupant-Hour Criterion (DOHC)	Sum of occupied hours multiplied by number of occupants and operative temperature exceeding the corresponding comfort range.	occupant group	single	yes	hourly	zone	occupant count	n.a.	n.a.	n.a.	n.a.			x		x	x	x	x						very high	n.a.	COMFORT
THERMAL	11. Discomfort Degree Days	The degree days when the indoor air temperature is outside the adaptive comfort temperature range. This metric can be divided into Cold Discomfort Degree Days and Hot Discomfort Degree Days.	occupant group	single	yes	hourly	zone	n.a.	n.a.	n.a.	n.a.	n.a.			x		x	x	x	x						very high	n.a.	COMFORT
THERMAL	12. Overheating /Overcooling Degree Days	The degree days that measure the degree of discomfort opposite of the building's assumed mode of operation (e.g., hot discomfort when the weather is cold, or cold discomfort when the weather is hot).	occupant group	single	yes	hourly	zone	n.a.	n.a.	n.a.	n.a.	n.a.			x		x	x	x	x						very high	energy	COMFORT
THERMAL	13. Indoor Discomfort Index	The absolute distance of the observed value to the defined optimum value (22°C with 45% relative humidity) relative to the preset comfort range (3°C and 10% relative humidity deltas) is used to estimate the IDI.	occupant group	single	yes	n.a.	zone	n.a.	n.a.	n.a.	n.a.	n.a.					x	x								low	n.a.	COMFORT

Domain	KPI Characteristics					Input Data Resolution			Normalization Factors				Quantifiability via Measurements: sensor, meters and/or required devices														Performance Goal	
	KPI	Definition	Occupant object	Value type	Dimensional	Temporal	Spatial	Occupancy	Temporal	Spatial	Occupant	Weather	N.A.	Occupancy	Occupant count	Illuminance	Temperature	Humidity	Air velocity	Radiant temperature	Co2 concentration	Tvoc	Particle matter	Decibel sound level	Timer	Measurement / calculation effort	Resources	IEQ
THERMAL	14. Overheating Risk Index	A metric indicating occupants' satisfaction to accumulated overheating stimuli (e.g., exceedance of a reference temperature of 25 °C).	occupant group	single	no	hourly	zone	presence	n.a.	n.a.	n.a.	n.a.					x								x	medium	n.a.	HEALTH
THERMAL	15. Radiant Asymmetry	The combined radiant temperature asymmetry in different directions at a point in a space.	n.a.	single or serial	yes	n.a.	single point	n.a.	n.a.	n.a.	n.a.	n.a.								x						low	n.a.	COMFORT
THERMAL	16. Thermal Autonomy	The percent of occupied time over a period where a thermal zone meets a set of thermal comfort criteria (e.g., operative temperature range) through passive means only.	occupant group	single	no	percent of time	zone	presence	time duration	n.a.	n.a.	n.a.		x												low	n.a.	COMFORT
AIR QUALITY	17. CO_2*Occupant Hour	The CO_2 concentration multiplied by occupant hour in a space.	occupant group	single	yes	hourly	zone	occupant count	n.a.	n.a.	n.a.	n.a.			x						x					high	n.a.	COMFORT
AIR QUALITY	18. Weighted Relative CO_2 Exceedance * Occupant Hour	The relative value of CO_2 exceeding a reference level, multiplied by the number of occupants and hours.	occupant group	single	yes	hourly	zone	occupant count	n.a.	n.a.	n.a.	n.a.			x						x					high	n.a.	COMFORT

KPI Characteristics						Input Data Resolution		Normalization Factors					Quantifiability via Measurements: sensor, meters and/or required devices														Performance Goal	
Domain	KPI	Definition	Occupant object	Value type	Dimensional	Temporal	Spatial	Occupancy	Temporal	Spatial	Occupant	Weather	N.A.	Occupancy	Occupant count	Illuminance	Temperature	Humidity	Air velocity	Radiant temperature	Co2 concentration	Tvoc	Particle matter	Decibel sound level	Timer	Measurement / calculation effort	Resources	IEQ
AIR QUALITY	19. Total Volatile Organic Compounds (TVOCs) * Occupant Hour	The total concentration of multiple airborne VOCs present simultaneously in the air multiplied by occupant hour in a space.	occupant group	single or serial	yes	hourly	zone	occupant count	n.a.	n.a.	n.a.	n.a.			x							x				high	n.a.	HEALTH
ACOUSTIC	20. Overall Sound Level	A frequency weighting curve to measure sound pressure level (usually refers to dB(A)).	n.a.	single	yes	n.a.	zone	n.a.	n.a.	n.a.	n.a.	n.a.												x		low	n.a.	COMFORT
ACOUSTIC	22. Time-averaged Sound Pressure Level (SPL)	The time-averaged sound pressure level that is used to indicate the sound level over a defined number of hours (usually for 8 working hours).	n.a.	single	yes	daily	zone	n.a.	hours	n.a.	n.a.	n.a.												x	x	medium	n.a.	COMFORT
ACOUSTIC	22. Reverberation Time (RT60)	The time required for the sound to reduce to a level 60 decibels below its original level.	n.a.	single	yes	sub hourly	zone	n.a.	n.a.	n.a.	n.a.	n.a.												x	x	low	n.a.	COMFORT
ACOUSTIC	23. Clarity Factor (C50)	The ratio of sound power present within at the beginning of the impulse response (usually 50 milliseconds), when early reflections occur, to the sound power present thereafter.	n.a.	single	no	n.a.	zone	n.a.	n.a.	n.a.	n.a.	n.a.												x	x	medium	n.a.	COMFORT

	KPI Characteristics					Input Data Resolution		Normalization Factors					Quantifiability via Measurements: sensor, meters and/or required devices														Performance Goal	
Domain	KPI	Definition	Occupant object	Value type	Dimensional	Temporal	Spatial	Occupancy	Temporal	Spatial	Occupant	Weather	N.A.	Occupancy	Occupant count	Illuminance	Temperature	Humidity	Air velocity	Radiant temperature	Co2 concentration	Tvoc	Particle matter	Decibel sound level	Timer	Measurement / calculation effort	Resources	IEQ
ACOUSTIC	24. Speech Transmission Index (STI)	A measure of speech transmission quality in noisy and/or reverberant environments.	n.a.	single	no	n.a.	zone	n.a.	n.a.	n.a.	n.a.	n.a.												x	x	high	n.a.	COMFORT
ACOUSTIC	25. Speech Intelligibility Index (SII)	A measure of speech intelligibility under adverse hearing conditions.	n.a.	single	no	n.a.	zone	n.a.	n.a.	n.a.	n.a.	n.a.												x	x	high	n.a.	COMFORT
ACOUSTIC	26. Speech Privacy Potential (SPP)	A metric indicating the level of perceived privacy between rooms (quantified by the sum of background noise level with the noise reduction).	n.a.	single	no	n.a.	zone	n.a.	n.a.	n.a.	n.a.	n.a.												x		low	n.a.	COMFORT
ACOUSTIC	27. Global Index of the Acoustic Quality	A global index that is the weighted function of five partial indices, namely: the reverberation index, the intelligibility of speech index, the uniformity of loudness index, the external disturbance index, and the music sound quality index.	n.a.	single	no	n.a.	zone	n.a.	n.a.	n.a.	n.a.	n.a.												x	x	high	n.a.	COMFORT

Source: adapted from (LI; WANG; HONG, 2021)